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CONDITIONING IN THE SPINAL DOG[1]

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Positive evidence that the spinal cord, when completely severed from the brain centers with which it is normally associated, is capable of establishing a substitute or 'conditioned' response (*CR*) has not hitherto been reported.[3] Heretofore the higher brain levels, whether of cortex (Pavlov, **9**, p. 330; Zeliony, **14**, p. 50 and p. 147; **15**, 181 *ff*) or of thalamus (Culler and Mettler, **4**, 607 *ff*; **3**, 291 *ff*; Girden, Mettler, Finch, and Culler, **8**, p. 383; Poltyrew and Zeliony, **11**, p. 157) have always been intact when conditioning was demonstrated. From evidence of this kind arose two widely accepted beliefs: (*a*) that spinal function is characterized by the

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[3] A motion picture and several reports covering various phases of this research have been presented in the last three years. These reports include: (1) "Observations on the Spinal Dog," E. A. Culler (in collaboration with P. S. Shurrager), Minneapolis meeting of the American Psychological Association, 1937; (2) "Conditioning and Related Phenomena in the Spinal Dog," P. S. Shurrager and E. A. Culler, Indianapolis meeting of the American Association for the Advancement of Science, 1937; (3) "Phenomena Allied to Conditioning in the Spinal Dog," and (4) the motion picture entitled "Phenomena Analogous to Conditioning in the Spinal Dog," P. S. Shurrager and E. A. Culler, Baltimore meeting of the American Physiological Society, 1938; (5) "Further Observations on 'Conditioning' and 'Extinction' in the Spinal Dog," P. S. Shurrager, Bryn Mawr meeting of the Eastern Psychological Association, 1939; and (6) doctoral thesis, "Conditioning in the Spinal Dog," University of Illinois, 1939.

transmission of nerve impulses along inherent reflex paths whose course is due not to conditioning but to processes of maturation; (*b*) that participation of some portion of the brain (cortex or thalamus) is, therefore, requisite for *all* conditioning. The implication of these doctrines that brain is something *new* in the evolution of nervous tissue, possessing unique (associative) properties such as are not found to any degree in the simpler mechanisms of the cord, has never, despite much plausible rationalization, been wholly convincing. Efforts have accordingly been made from time to time to institute conditioning within the functional framework of the cord; but the spinal animal looks and acts so very unlike the normal intact animal with which the conditioning procedure was first employed and developed that crucial evidence is hard alike to secure, to recognize, and to evaluate. "Severance of the cord in higher mammals (cat, dog, monkey) produces at once a limp quietude of the skeletal muscles aboral from the transection; and even when the whole segmental length of the cord is so included. This muscular inactivity comprises absence of active attitude" (Creed, *et al.*, 1, p. 151). This quiescence of the skeletal musculature 'proves on analysis to mean quiescence of the reflex organ,' which thus provides a 'clean background of passive quiescence' for the study of spinal coördination (p. 155). These statements have been widely accepted by physiologists and psychologists alike; 'absence of active attitude' and 'background of passive quiescence' being taken to imply (whether correctly or not) the absence of modifiable response mechanisms (*CR*) in the cord as well.

In these precursive remarks are implied the problem and purpose of this investigation. Is an isolated segment of the spinal cord, when its sensory and motor peripheral mechanisms are preserved intact, capable of *acquiring* substitute responses (*i.e.*, of establishing new sensori-motor connections) which were not reflexively present after transection? In short, is spinal conditioning possible; and, if so, what is the nature of the thus created *CR* and of the mechanisms by which it operates?

Throughout the paper the accepted terminology[4] of conditioning and extinction is employed. This usage is not an effort to forestall the question: are these phenomena *really comparable* to those which attend the rise and fall of conditioning in dogs with complete or partial brain? To this question the present paper gives an affirmative answer by demonstrating that, if the spinal preparation be subjected to the same experimental procedures ('operations') which induce conditioning and extinction in the normal dog, certain effects appear which exhibit an unmistakable kinship to those manifested by normal animals under similar conditions.

Methodology.—A. Operative Procedure.—Dogs ranging from two months to two years of age were found to be best adapted to the problem, though conditioning has been demonstrated in very young puppies (three to five days after birth),[5] kittens (at birth), as well as older cats and dogs. This paper is confined to observations in dogs. The operative procedure employed in these experiments is substantially as follows:

1. Under complete ether anesthesia, the dog is tracheally cannulated. When the transection is made in the cervical region above the respiratory spinal roots (fifth, sixth, and seventh cervical) of the phrenic nerve (Ellenberger and Baum, **5**, p. 540) mechanical respiration is required.

[4] The terminology and abbreviations used in this paper are: (1) *UCS* (unconditioned stimulus), electric shock to the hind-paw; (2) *CS* (conditioned stimulus), a slight stimulation, electric or mechanic, applied to the tip of the tail; (3) *UCR* (unconditioned response), a full flexion of the M. S–T (semitendinosus muscle) in response to the *UCS*; (4) *CR* (conditioned response), the acquired or substitute reaction of a portion of the M. S–T in response to the *CS*; (5) conditioning, the process of combining the *CS* and *UCS* in such a way that *CS*, when presented alone, comes to elicit the *CR*; (6) extinction, the process by which an existing *CR* is abolished when the *CS* is repeatedly presented without reinforcement; (7) reconditioning, the procedure of repeating the conditioning process after one or more extinctions; (8) reëxtinction, the procedure of repeating the extinction process after two or more conditionings; (9) *ces* (central excitatory state), the term (c.e.s.) used by Sherrington to designate the physiological processes which are initiated in the cord by peripheral stimuli; (10) central conditioning, the synaptic change which occurs during conditioning as differentiated from the peripheral muscular *CR*; and (11) central extinction, the synaptic change which occurs during extinction as differentiated from the failure of the peripheral muscular *CR*.

Physiological readers are reminded that the *CR* reflex twitch belongs to a different category than does the so-called 'spinal reflex.' The spinal *CR* (*a*) extinguishes with repeated (unreinforced) *CS*s and (*b*) does not summate with a continuous *CS* or series of *CS*s (see *Methodology*, B 1, 3, 4, and 6, and C). Because the spinal *CR* is different from spinal reflexes in these two points, it is labelled a conditioned response rather than a conditioned reflex.

[5] See footnote 3, *op. cit.*, 1937 (2).

2. Transection may be effected at any level between the cervical and the third lumbar spinal roots (see Fig. 1). The cord, after being fully exposed for approximately four centimeters, is first securely ligated in two places about two centimeters apart with strong linen thread and is then, with iridectomy scissors, completely severed midway between the ligatures. Ligation prevents the escape of cerebro-spinal fluid both above and below the transection and thus helps maintain the fluid at relatively normal pressure within the nervous system. In this way vascular reflexes are presumably less impaired and blood-pressure better maintained throughout the animal. Ligation serves also to obviate drying and to maintain the proper mechanical and chemical medium for the meningeal membranes of the cord. Were the cerebro-spinal fluid allowed to escape, the consequent collapse of the dura and the weight of the cord tissues might also tend to compress the blood-vessels and thus impair the blood-supply.

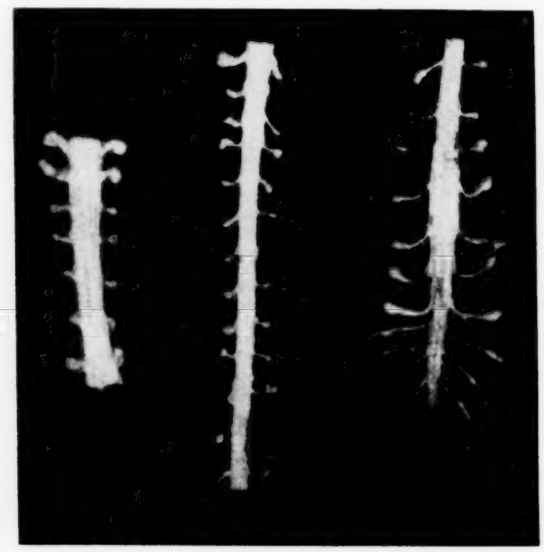

FIG. 1. Photograph of the spinal cord of the dog showing (*A*) the cervical cord; (*B*) the thoracic cord; and (*C*) the lumbar and sacral cord. The spinal roots are severed just beyond the dorsal root ganglia in each case.

For those experiments in which functional delimitation of the lumbar region was desired, the whole dorsal surface of the lumbar cord was exposed. In still other animals, where the effect upon the *CR* of successively smaller amounts of cord-mass was tested, the whole length of the spinal cord, from cervical to sacral, was exposed.

3. Both MM. S–T (semitendinosus muscles) are exposed by incising and reflecting the overlying skin; they are then freed from their fascial attachments, the nerve- and blood-supplies being carefully preserved. Each tendon is severed from its insertion on the proximal end of the tibia, while the bony surface where it originates from the ischium is chipped free and left attached to the muscle. The whole muscle is thus freed at both ends, being connected only by nerve- and blood-supplies to the animal. The M. S–T is easily accessible, since it directly underlies the skin which forms the posterior contour of the femoral portion of the hind-limb.

4. The hind quarters are rigidly held by means of a drill-rod which pierces both femurs and is clamped at each end to the uprights of a U-shaped support. The hind legs are thus firmly fixed between the two uprights and the ischial origin of each muscle

is secured to a pin in the base of the support. The limbs and the holder in which they are fastened may be held in either position, inverted or upright.

5. The tendon of each muscle is attached to a kymograph lever and simultaneous contralateral records of responses to both the *CS* (conditioned stimulus) and *UCS* (unconditioned stimulus) are taken. Since the *CR* is in most cases a minute twitch of the distal end of the M. S–T and regularly appears in a pit-like portion of the muscle near its tendon of insertion, it is necessary to attach a series of fine silk threads to the surface fascia in this region, draw these taut, and attach them all to a single thread which is led off from the tendon and is in turn attached to the kymograph lever. In this way a movement of the threads in the fascia can act upon the lever as well as does a movement of the tendon itself.

B. Conditioning and Extinction Procedures.—Conditioning and extinction are readily alternated in most spinal dogs, though some preparations lend themselves to both processes more readily than others. The conditioning and extinction procedures (see Figs. 2 and 3) and experiments may be outlined as follows:

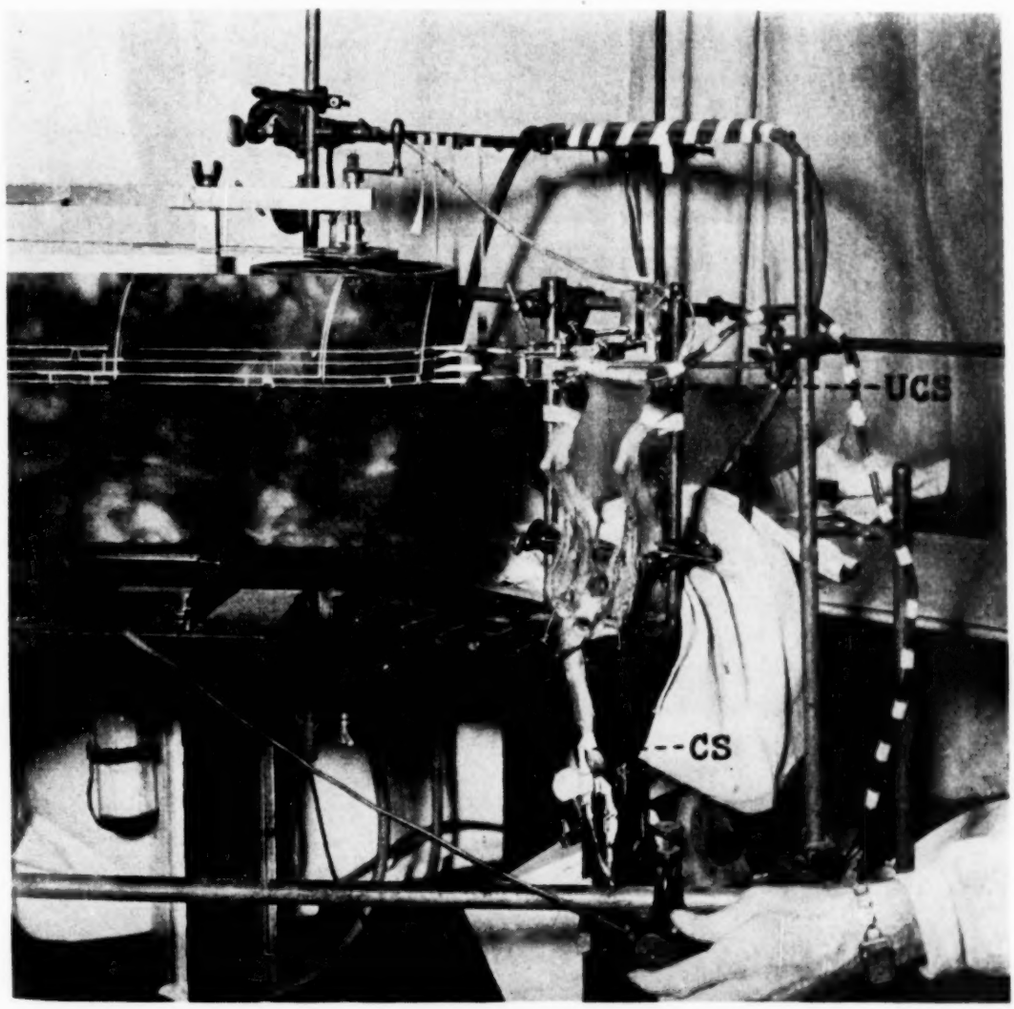

FIG. 2. General view of apparatus for spinal conditioning. In this animal the spinal cord is transected, the hind-limb flexors (MM. semi-tendinosus) are dissected out and attached to writing-levers which record the muscle-contractions on smoked paper.

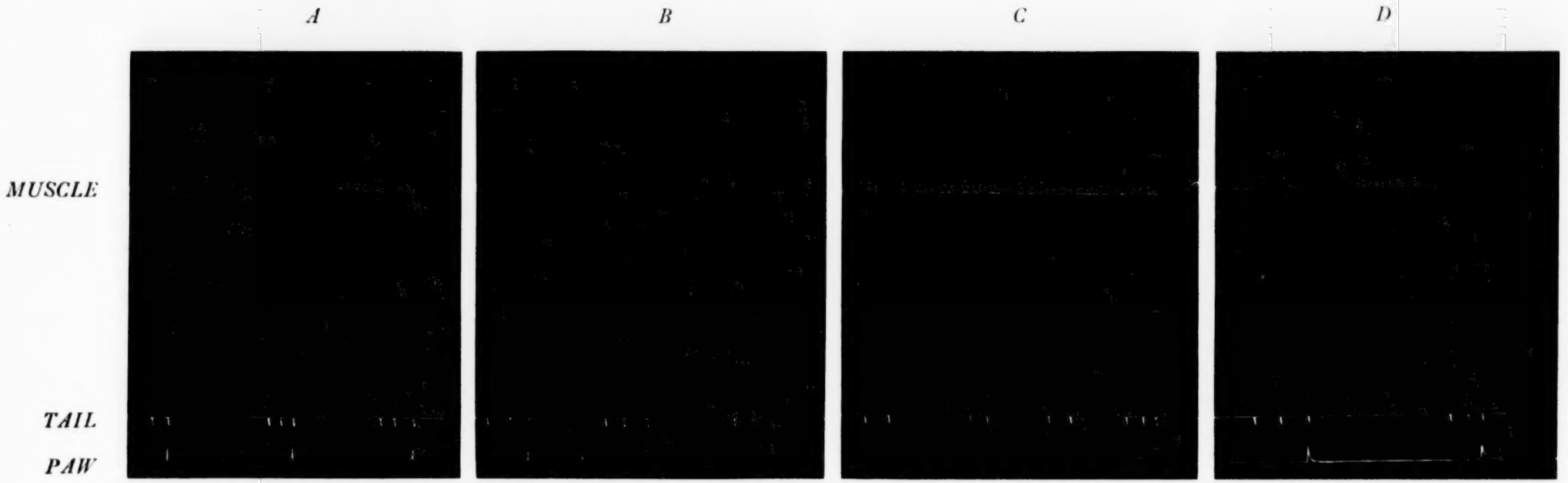

FIG. 3. Kymograph records of conditioning, extinction, and reconditioning. (*A*) three conditioning trials before the conditioned response is evidenced; (*B*) three conditioning trials after the conditioned response is evidenced; (*C*) the last stages of extinction and the first reconditioning trial; and (*D*) two trials of reconditioning.

1. The *CS* is always applied to the tail. In most cases it consists of a moderate A.C. shock of short duration [6] (the flick of a push-button switch); but D.C. stimuli of constant milliamperage from a chronaximeter (pentode controlled square-pulse generator), rectified A.C. stimuli of constant milliamperage, and the quick uniform tap of a stiff-bristled brush have been used successfully in the conditioning technique. Inasmuch as tactile sensitivity varies greatly in dogs, the exact intensity of the stimulus is relative; but its intensity is kept constant [7] throughout the experimentation with any individual animal whose records are used.

2. The *UCS* is in every case an A.C. shock or a rectified current with constant milliamperage of sufficient magnitude to elicit a full contraction of the M. S–T when applied to the homolateral hindpaw.

3. The conditioning procedure is always preceded by a series of *CS*s (30 to 60 in number) applied to the tail, in order to make certain that the *CR* (muscle twitch) can not be elicited from the M. S–T merely by repeated administrations of the *CS* prior to conditioning.

4. The technique usually employed consists in applying (1) the *CS* (tail shock) alone, then one second later (2) the *CS* again alone, finally one second later (3) both *CS* and *UCS* together. This sequence is repeated at intervals of fifteen, thirty, or sixty seconds. The *UCS* (paw shock) is applied whether the *CR* appears or not, so that the conditioning procedure is kept constant throughout the series.

5. A rest period, ten minutes or longer, is interposed between the conditioning and extinction period to make sure that the *CR* is a stable response. In reconditioning and reëxtinction a similar interval is interposed after each conditioning and extinction series.

6. The extinction process is a repetition of the conditioning process with the same temporal intervals, except that the *UCS* is omitted (see Fig. 3, *C*). The fifteen-, thirty-, or sixty-second interval is interposed between each two trials as in the preceding conditioning sequence.

7. During conditioning and extinction the contralateral (right) M. S–T is closely observed. It remains flaccid throughout both processes.

C. Controls.—Numerous checks designed to test whether the spinal *CR* satisfies the standard criteria for conditioning and extinction will next be discussed.

Certain accepted criteria for the *CR* may be stated as follows: (1) the *CR* is not present upon the original presentation of the *CS*; (2) the *CR* appears upon presentation of the *CS* only after reinforcement with the *UCS* in the conditioning process; and (3) the *CR* is extinguishable. The checks made to determine whether or not the spinal *CR* meets these criteria are outlined below.

1. Repetitions of the *CS* (three tail-shocks at one-second intervals) at the usual experimental periods of fifteen, thirty, and sixty seconds, as well as at shorter intervals of ten and five seconds, have never been observed to elicit a response of the muscle prior to conditioning though continued through more than two hundred trials with dogs specifically used for checking this point. Consequently, the routine procedure with each animal of administering thirty to sixty repetitions of the *CS* before beginning

[6] The A.C. current consists of 60 complete cycles or 120 single stimuli of equal duration; each unit-stimulus therefore lasts 1000/120 or 8.33 milliseconds.

[7] It is true, however, that the amperage of the A.C. current which was used as *CS*, not having been controlled with compensating devices such as were used in the rectified A.C. shocker, may have varied slightly owing to changes in tissue-resistance.

the conditioning process seems to be an adequate precaution against mistaking some inherent reflex of the muscle for a conditioned response.

2. (*a*) Repetitions of the *UCS* (three paw-shocks at one-second intervals) alternating with a series of *CS*s (three tail-shocks at one-second intervals) with variable time relations have never produced a response to the *CS*.[8]

(*b*) Repetitions of the *UCS* followed by two *CS*s have never given rise to the *CR* even when continued through as much as one hundred trials.[8]

3. (*a*) Repetitions of the *CS* alone, after the *CR* is readily elicited, have shown the *CR* to fail even though the *CS*s are presented in the same temporal order as was used in the conditioning process. The failure of the *CR* is gradual and follows a course which is inverse to its growth during the conditioning process.

(*b*) The *CR* is stable and is not extinguished merely by temporal delay, without the *CS*s being presented. In fact, temporal delay of as much as nine hours has shown the *CR* to be elicited by the first application of the *CS* and still to be readily extinguishable when the *CS* is presented without reinforcement in the regular extinction process.[9]

4. Can the *CR* be explained as due to the increasing response of a spinal mechanism as the animal emerges from anesthesia, the reflex being at first attenuated and later returning to its full stature?

The answer to this question is negative for two reasons: (1) Since other spinal reflexes (*e.g.*, squirming of tail when *CS* is applied to tip and stretch-reflex of M. S–T) may readily be elicited either during etherization or at least within ten minutes after ether is stopped, it seems obvious that the tail-to-muscle response would appear within two hours (usual delay between operation and test-period) were it also a spinal reflex; (2) the *CR* would not then be extinguishable.

5. The fact that these phenomena can be readily elicited by use of a mechanical stimulus (tapping tip of tail with a stiff brush) alone proves that they are not artifacts

[8] Were backward conditioning possible in this specific experimental situation, it should have appeared during the course of these extensive tests.

[9] These time-relations seem to nullify any explanation based directly upon the 'central excitatory state' of Sherrington and his collaborators. This c.e. state is the 'enduring' excitatory condition set up by a centripetal volley (1, p. 32); and because of its persistence for some milliseconds, summation of centripetal volleys occurs not only when they are exactly coincident but also when they are separated by as much as ten to twenty msec. Within these stimulus-intervals "the excitatory condition produced by one volley sums with that produced by the other and sets up a reflex discharge"; the summation probably occurring at the 'actual convergence points on the motoneurone' (1, pp. 31–33). Inasmuch as the temporal interval between *UCS* (paw-shock) which terminates a given trial and the *CS* (tail-shock) which initiates the next trial is never less than fifteen seconds, and is often many minutes or even several hours, it is clear that the time-relations in conditioning are wholly different in order of magnitude from those which underlie reflex facilitation in the spinal mammal during the persistence of the central excitatory state. But since the stimulation is applied in conditioning, not to the nerve-fiber as in Sherrington's work, but to the cutaneous receptors of the hind-paw, the end-organ is likely to continue firing after the *UCS* stops for at least a few msec. and possibly much longer. But even were the hindpaw-endorgan to continue an intermittent discharge during the whole fifteen-second period from one paw-shock until the next tail-shock, this fact would still not serve to explain conditioning (see *Controls*, 2, a and b).

due to direct electric stimulation. Were the response of M. S–T referable to direct action of the *CS* (tail-shock) either upon the muscle itself or upon its nerve-supply, one of two conditions would need to be operative: (*a*) current passing by or through M. S–T between tail-electrodes and paw-electrodes; (*b*) spread of the electric field created by the two tail-electrodes. If (*a*) alone were true, removal of the pawleads would cause the apparent *CR* to cease. This does not occur. If either (*a*) or (*b*) were true, (1) we should expect the apparent *CR* to occur on the *first* trial without preliminary conditioning. (2) The *CR* again would not extinguish. (3) Gradual removal of the *CS*-leads from tip of the tail towards flanks, thus bringing them nearer M. S–T, would decrease the ohmic resistance of the current-path and thus increase the magnitude of *CR*. (4) Raising the intensity of *CS* would likewise increase the magnitude of *CR*. Not one of these expectations is realized.

Results.—A. General Statement.—The data presented in this paper are based upon experimental evidence secured from two hundred and nineteen spinal dogs, in ninety-eight of which conditioned responses were elicited and later extinguished. Since the criteria for 100 percent conditioning and extinction were first determined in the course of preliminary experimentation, conditioning was not continued long enough in eighteen of these ninety-eight cases to permit their inclusion in Tables I to IV. In addition to the checks made upon each individual preparation, twenty-three dogs were specifically used as *controls* of one kind or other to demonstrate that the conditioning and extinction evidenced in these spinal animals are not artifacts due to such factors as (1) direct stimulation, (2) time elapsing between operation and test period, (3) increased excitability of the neural and muscular systems by which the threshold of sensitivity of the preparation to the stimulus for an innate reflex might be lowered, or (4) phenomena which could be aroused by other than the conditioning and extinction processes. In the end, complete conditioning records were obtained from fifty-seven dogs (Table I).

B. Minimum Amount of Cord Necessary for Eliciting the Spinal CR.—The MM. S–T are regularly innervated by the sixth and seventh lumbar and first sacral roots (as can be empirically determined by direct stimulation of the motor roots). Systematic serial sections anterior to these roots show that transection of the spinal cord behind the third lumbar roots results in the failure of the spinal reflexes aboral to the transection and likewise of the *CR*.[10]

[10] See footnote 3, *op. cit.*, 1937 (2).

In the case of two litter-mates, however, spinal section as high as the first lumbar roots eliminated the response. The only explanation for the failure of these two animals to respond after the cord had been divided at least two segments higher than usual appears to reside in circulatory anomalies. They differed from other dogs studied in that the largest visible vein and artery serving this region of the cord entered along the first lumbar roots. Severance below these roots thus necessitated ligation of these blood-vessels. In the other dogs studied, these larger vessels entered along the third lumbar roots. It appears that the small vessels which enter the cord aboral to the large vessels here mentioned are either

TABLE I

PERCENTAGE OF CONDITIONED RESPONSES IN SUCCESSIVE TENTHS OF THE WHOLE NUMBER OF TRIALS REQUIRED FOR COMPLETE CONDITIONING IN FIFTY-SEVEN SPINAL DOGS

Dog No.	Successive Tenths										Trials
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	
1	33	0	33	100	100	100	67	100	100	100	30
2	0	0	0	50	50	25	75	100	100	100	40
3	0	29	0	57	29	29	29	0	100	100	70
4	40	30	20	50	30	10	50	60	50	100	100
5	0	20	60	0	60	80	80	100	100	100	50
6	17	17	67	33	50	100	83	100	100	100	60
7	0	0	33	33	67	100	100	100	100	100	30
8	0	50	100	100	100	100	100	100	100	100	20
9	25	0	75	25	75	100	75	100	100	100	40
10	0	50	33	50	67	100	83	100	100	100	60
11	0	0	60	60	40	100	80	100	100	100	50
12	0	33	33	0	100	67	100	100	100	100	30
13	0	0	60	60	60	80	80	100	100	100	50
14	0	0	40	80	60	100	60	100	100	100	50
15	0	75	25	25	25	50	75	25	75	100	80
16	0	0	0	20	80	100	40	80	100	100	50
17	50	25	50	75	75	100	75	100	100	100	40
18	50	10	50	40	90	90	70	70	70	100	100
19	33	0	33	100	100	100	67	100	100	100	30
20	0	75	25	25	25	50	75	25	75	100	120
21	0	67	67	33	100	100	100	100	100	100	30
22	0	67	33	33	0	100	100	100	100	100	30
23	0	50	75	50	100	75	100	100	100	100	40
24	0	50	75	50	100	75	100	100	100	100	40
25	0	33	67	67	100	67	100	100	100	100	30
26	0	25	75	75	100	100	75	100	100	100	40
27	0	25	50	75	100	75	100	100	100	100	40
28	0	25	50	75	75	100	75	100	100	100	40
29	0	25	50	0	0	50	75	100	100	100	40
30	0	20	0	60	80	100	80	100	100	100	50

TABLE I—*Continued*

Dog No.	Successive Tenths										Trials
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	
31	0	0	50	100	100	50	0	50	100	100	60
32	0	0	40	80	60	100	100	60	100	100	50
33	0	0	40	80	60	80	80	100	100	100	50
34	0	0	33	67	100	100	67	67	100	100	60
35	0	0	25	50	75	25	25	75	100	100	80
36	0	0	0	50	75	100	75	100	100	100	40
37	0	0	0	50	50	25	75	100	100	100	40
38	0	0	0	25	0	50	75	75	100	100	80
39*	0	0	0	50	50	25	75	100	100	100	40
40*	17	33	0	17	100	67	67	100	100	100	60
41*	0	60	40	20	40	80	40	100	100	100	50
42*	0	67	67	67	100	100	100	100	100	100	30
43*	0	100	100	100	100	100	100	100	100	100	20
44*	0	25	50	75	100	100	75	100	100	100	40
45*	0	67	67	67	33	100	100	100	100	100	30
46*	0	0	100	100	20	20	100	100	100	100	25
47*	0	0	0	67	67	100	100	100	100	100	30
48*	33	0	33	100	100	100	67	100	100	100	30
49*	0	0	50	100	0	100	100	100	100	100	20
50*	0	100	100	100	100	100	100	100	100	100	20
51*	0	0	60	60	60	80	80	100	100	100	50
52*	0	25	75	100	100	75	100	100	100	100	40
53*	33	50	0	33	83	17	83	83	100	100	60
54*	33	100	100	67	100	67	100	100	100	100	30
55*	0	25	50	25	50	50	75	100	100	100	40
56*	0	33	67	67	67	67	100	100	100	100	30
57*	0	0	0	20	0	0	20	20	100	100	50
Mean (1–57)	6.4	26.1	43.6	56.6	67.2	75.5	77.9	89.3	97.7	100.0	46.23
Mean (1–38)	6.5	21.1	40.2	52.7	67.3	77.7	75.4	86.5	96.6	100.0	51.05

Dog. no. 1 first attained a perfect record (10 *CR* in 10 successive trials) in the third decade, trials 21 through 30; in the first three trials (1st tenth), it scored one *CR* or 33 percent. Dog no. 3 did not reach the criterion until the seventh decade, trials 61 through 70; in the second set of seven trials (2nd tenth), it scored two *CR* or 29 percent.

inadequately anastomosed or else carry insufficient blood to maintain the cord functionally. If both sensory and motor roots of the third, fourth, fifth, and sixth lumbar segments are cut on each side of the cord, with the blood-supply being fully preserved where it enters at the third lumbar level, the usual spinal reflexes (such as response to paw-shock) persist and the *CR* to tail-shock can be created and preserved. This observation demonstrates (1) that the named sensory and motor roots are not essential to either the spinal reflexes or the *CR*, and (2) that severance of these roots may leave the mass of the cord at these levels still functional.

TABLE II

PERCENTAGE OF CONDITIONED RESPONSES IN SUCCESSIVE TENTHS OF THE WHOLE NUMBER OF TRIALS REQUIRED FOR COMPLETE EXTINCTION IN THIRTY-EIGHT SPINAL DOGS

Dog No.	Successive Tenths										Trials
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	
1	100	100	100	89	100	100	89	89	56	0	90
2	100	100	50	0	0	0	0	0	0	0	20
3	100	100	50	0	0	50	0	0	0	0	40
4	100	67	33	50	17	33	33	17	0	0	60
5	83	50	33	17	33	33	33	0	33	0	60
6	100	50	75	50	50	0	25	25	0	0	40
7	100	100	100	100	0	0	0	0	0	0	20
8	100	67	67	100	100	33	33	0	0	0	30
9	100	50	50	0	0	0	0	0	0	0	20
10	100	67	33	50	17	33	33	17	0	0	60
11	100	100	100	0	0	0	0	0	0	0	20
12	100	100	50	50	0	0	0	0	0	0	20
13	100	100	89	33	100	100	100	78	11	0	90
14	80	60	20	40	80	20	20	40	0	0	50
15	100	100	33	0	33	33	0	0	0	0	30
16	80	20	0	20	0	20	40	0	0	0	50
17	100	100	100	0	0	0	0	0	0	0	20
18	89	100	78	89	89	100	56	11	11	0	90
19	100	75	75	75	25	25	25	25	0	0	40
20	80	60	40	40	20	20	20	60	0	0	50
21	75	25	25	25	50	0	0	25	0	0	40
22	100	33	33	67	33	33	33	0	0	0	30
23	80	40	40	60	20	0	20	0	0	0	50
24	67	100	0	0	0	33	0	0	0	0	30
25	100	100	100	100	0	0	0	0	0	0	20
26	100	100	100	50	50	25	0	0	0	0	40
27	100	67	33	50	17	33	33	17	0	0	60
28	90	70	40	70	90	70	30	40	20	0	100
29	100	100	33	66	0	0	0	0	0	0	30
30	100	100	50	0	0	0	0	0	0	0	20
31	88	100	100	75	75	88	100	75	0	0	80
32	100	83	83	17	67	50	17	0	17	0	60
33	87	73	60	33	53	20	13	7	7	0	150
34	75	50	75	25	100	50	25	0	0	0	40
35	100	43	71	71	43	43	29	43	43	0	70
36	100	100	100	89	56	44	33	44	56	0	90
37	100	33	66	66	33	33	33	0	0	0	30
38	83	50	33	17	33	33	33	0	17	0	60
Mean	93.6	74.8	58.4	44.3	38.0	29.1	20.7	16.1	7.1	0.0	49.2

Dog no. 5 first attained a perfect record (0 *CR* in 10 successive trials) in the sixth decade, trials 51 through 60. In the first set of six trials (1st tenth) it scored five *CR* or 83 percent, whereas in the second set of six trials (2nd tenth), it scored three *CR* or 50 percent. These 38 dogs are the same in order as dogs 1–38 in Table I.

TABLE III

PERCENTAGE OF CONDITIONED RESPONSES IN SUCCESSIVE TENTHS OF THE WHOLE NUMBER OF TRIALS REQUIRED FOR COMPLETE CONDITIONING IN SUCCESSIVE CONDITIONING AND RECONDITIONING SERIES IN SIX SPINAL DOGS

Conditioning Series	Successive Tenths										No. of Trials
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	
Animal no. 1											
1	0	0	0	50	75	100	75	100	100	100	40
2	0	50	0	100	50	100	100	100	100	100	20
3	0	50	100	100	100	100	100	100	100	100	20
4	50	100	100	100	100	100	100	100	100	100	20
5	50	100	100	100	100	100	100	100	100	100	20
6	50	100	100	100	100	100	100	100	100	100	20
Animal no. 2											
1	0	0	20	40	60	80	80	80	100	100	50
2	0	50	100	100	100	100	100	100	100	100	20
3	0	100	100	100	100	100	100	100	100	100	20
4	50	100	100	100	100	100	100	100	100	100	20
5	50	100	100	100	100	100	100	100	100	100	20
6	50	100	100	100	100	100	100	100	100	100	20
Animal no. 3											
1	0	67	67	67	33	100	100	100	100	100	30
2	50	100	50	100	100	100	100	100	100	100	20
3	50	50	100	100	75	100	100	100	100	100	20
4	50	100	100	100	100	100	100	100	100	100	20
Animal no. 4											
1	43	14	14	43	43	14	43	43	100	100	70
2	50	50	100	100	100	100	100	100	100	100	20
3	50	100	100	100	100	100	100	100	100	100	20
4	0	100	100	100	100	100	100	100	100	100	20
Animal no. 5											
1	0	0	0	33	67	67	100	100	100	100	30
2	0	50	100	50	100	100	100	100	100	100	20
3	50	100	100	100	100	100	100	100	100	100	20
4	50	100	100	100	100	100	100	100	100	100	20
Animal no. 6											
1	0	0	40	40	80	70	90	90	90	100	100
2	25	50	75	50	75	100	75	100	100	100	40
3	50	50	50	100	100	100	100	100	100	100	20
4	50	100	100	100	100	100	100	100	100	100	20

TABLE IV

PERCENTAGE OF CONDITIONED RESPONSES IN SUCCESSIVE TENTHS OF THE WHOLE NUMBER OF TRIALS REQUIRED FOR COMPLETE EXTINCTION IN SUCCESSIVE EXTINCTION AND REËXTINCTION SERIES IN SIX SPINAL DOGS

Extinction Series	Successive Tenths										No. of Trials
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	
Animal no. 1											
1	100	100	100	89	100	100	89	89	56	0	90
2	90	80	40	70	100	70	50	40	30	0	100
3	100	50	50	0	0	0	0	0	0	0	20
4	100	50	0	0	0	0	0	0	0	0	20
5	50	50	0	0	0	0	0	0	0	0	20
6	50	0	0	0	0	0	0	0	0	0	20
Animal no. 2											
1	100	100	50	0	0	0	0	0	0	0	20
2	100	100	0	0	0	0	0	0	0	0	20
3	100	50	0	0	0	0	0	0	0	0	20
4	50	0	0	0	0	0	0	0	0	0	20
5	50	0	0	0	0	0	0	0	0	0	20
6	50	0	0	0	0	0	0	0	0	0	20
Animal no. 3											
1	100	100	50	0	50	0	0	0	0	0	20
2	100	100	0	0	0	0	0	0	0	0	20
3	100	50	0	0	0	0	0	0	0	0	20
4	100	100	100	0	0	0	0	0	0	0	20
Animal no. 4											
1	100	67	33	50	17	33	33	17	0	0	60
2	100	100	100	0	0	0	0	0	0	0	20
3	100	100	0	0	0	0	0	0	0	0	20
4	100	100	50	50	0	0	0	0	0	0	20
Animal no. 5											
1	85	50	33	17	33	33	33	0	33	0	60
2	75	50	25	25	50	0	0	25	0	0	40
3	75	25	25	0	25	0	25	0	0	0	40
4	100	0	0	25	0	0	0	0	0	0	40
Animal no. 6											
1	100	50	75	50	50	0	25	0	25	0	40
2	100	0	50	0	0	0	0	0	0	0	20
3	50	50	100	0	0	0	0	0	0	0	20
4	50	50	0	0	0	0	0	0	0	0	20

The least possible amount of cord-mass necessary for establishing the *CR* cannot however be definitely ascertained by this procedure of delimiting the cord by serial transection and successive severance of the roots from one level to the next, for the reason that the cord cannot be excised below third lumbar without depriving the remaining cord of its requisite blood-supply.[11] If the seventh lumbar segment could be adequately supplied with blood by other means, it seems likely that the *CR* (response of M. S–T to tail-shock) could be established and maintained even if all segments anterior thereto had been removed. In other words, we assume that the cord-mass between the third and sixth lumbar is not essential for conditioning; but obviously this assumption can be proved only by recourse to histological evidence from chronic preparations or electrical recording.

A series of transections carried through for the purpose of comparing preparations with graded residual amounts of spinal cord, has shed some light upon the problem. Transection of the spinal cord in the region of the second cervical roots *after* the animal had been conditioned to react to tail-shock by contracting M. S–T showed that the *CR* which persisted after transection had decreased in size from the former full contraction to the very localized response characteristic of the *CR* in the spinal animal. Repeated transections of the cord at every third or fourth root aboral to the initial cervical transection show that the *CR* is not altered by subsequent transections until it, together with the spinal reflexes, is eliminated when the blood-supply is impaired in the region of the third lumbar roots.

The absence of quantitative or qualitative difference in the spinal *CR* for unequal amounts of intact spinal cord-mass, along with the lack of variation in magnitude or loss of *CR* when the separate roots are severed below the blood-supply as above indicated, would lead to the hypothesis that *CR* in the spinal animal is dependent upon available synaptic con-

[11] In a recent publication Suh and Alexander (13) describe and diagram but do not name this posterior radicular artery in the human spinal cord. It seems that in the dog, this artery has great functional significance, at least in the lumbo-sacral spinal preparation described here.

nections at the level of *its own* spinal roots and is not appreciably affected by sensory or motor nerve components, nor probably by gray mass, anterior to them. Evidence is still inadequate to allow the hypothesis to be offered without reservation, especially as to the effect of the remaining spinal cord-mass in the lumbar region.

C. The Original Conditioning and Original Extinction.— The criteria which were imposed for 100 percent conditioning and extinction in the spinal preparation were designed to be conservative. Every successive ten trials was considered as a single test-unit and conditioning was continued until the preparation responded every time in one of these decadal units. Thus, if the animal responded perfectly for trials eleven through twenty, or twenty-one through thirty, or eighty-one through ninety, it had met the criterion for conditioning. Likewise, extinction was determined by complete failure to respond in one of the decadal units. A criterion such as the above, since it is based upon ten-trial units, makes it possible to plot Vincent-curves for the data without recourse to interpolation. All that is necessary is to plot percent trials against percent response or percent failure to respond.

Data representing the original conditioning records for fifty-seven spinal dogs are given in Table I. Table II shows the extinction of the *CR* subsequent to the original conditioning in thirty-eight of these dogs. Extinction records for the last nineteen of the fifty-seven preparations whose original conditioning records are given in Table I do not appear in Table II. Various tests were made with these nineteen animals after the original conditioning and before extinction was begun. Because these checks were interpolated between the conditioning and extinction processes with the last nineteen preparations, extinction figures obtained from them are not strictly comparable to those obtained from the remaining thirty-eight animals and are therefore not included in Table II.

The data given in Table II are graphically presented as mean Vincent-curves in Fig. 4.[12] The original conditioning

[12] See footnote 3, *op. cit.*, 1939.

curve for all fifty-seven animals is represented by large open circles joined by a solid line. The original extinction curve is shown in the right-hand diagram of Fig. 4 by small open circles with solid line. Since the extinction curve is not based upon data obtained from the entire original group of animals, it seemed advisable to plot separately the original mean conditioning curve for the thirty-eight animals which are included in the extinction curve in order that the two processes may be compared in the same animals. The conditioning curve

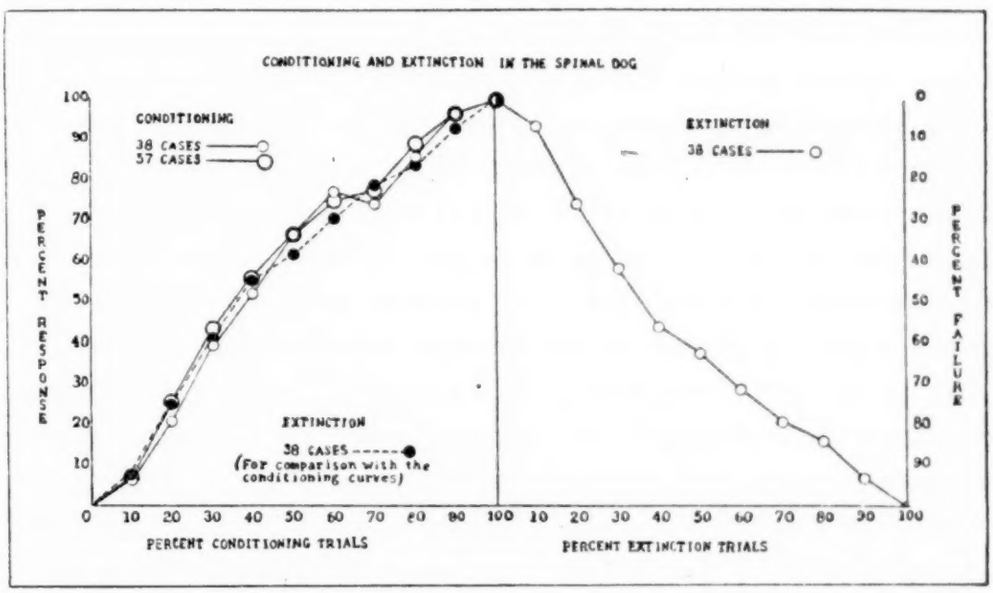

FIG. 4. Vincent-Curves of original conditioning and extinction in the spinal dog. Small open circles, conditioning and subsequent extinction in thirty-eight preparations. Large open circles, conditioning in fifty-seven preparations. Solid circles and dotted line, extinction curve turned vertically through 180° and superposed upon the conditioning curves for comparison.

for the smaller group is shown by the small open circles and solid line in the left-hand diagram of Fig. 4. Obviously, the conditioning curve for the thirty-eight animals upon whose data the extinction curve is based is virtually identical with the conditioning curve of the larger group of fifty-seven animals.

D. The Relation between Conditioning and Extinction.—In order to determine the degree of similarity between the extinction curve shown in the right-hand diagram of Fig. 4 and the two conditioning curves, the extinction curve was turned vertically through 180° and superposed upon the condition-

ing curves in the left-hand diagram. The superposed curve is shown in solid circles and broken line. The conditioning and extinction curves appear to be approximately identical throughout their courses. Such striking similarity in the curves of conditioning and extinction suggests a similarity in the fundamental mechanisms of conditioning and extinction.

If an essential similarity exists, it should become increasingly apparent as the processes of conditioning and extinction are repeatedly alternated in the same preparation. A series of curves from such a preparation must show one of several possible relationships between conditioning and extinction. These relationships are: (1) repeatedly conditioning and extinguishing a preparation may make no change in the slope of the curves or in the number of trials necessary for establishing and abolishing the *CR*; (2) one curve may vary while the other retains its original slope; (3) the slope of both reconditioning and reëxtinction curves may so change as to reveal either a direct or an inverse relationship between the number of trials necessary for establishing the conditioned response and subsequently extinguishing it. If after a series of conditionings and extinctions the curves are virtually identical with the original conditioning and extinction curves, or if there has been a marked change in the slope of the curves and this change has been in the same direction, so that the ratio of conditioning and extinction trials is practically the same for the last series as for the first series, it may reasonably, though not certainly, be inferred that the processes of conditioning and extinction utilize similar synaptic mechanisms.

In order to test the hypothesis that the mechanisms of conditioning and extinction are similar, data were secured from four preparations in which the two processes were alternated through the third reconditioning and reëxtinction (fourth conditioning and extinction) with rest periods of not less than ten minutes between successive series, and from two preparations in which the processes were alternated through the fifth reconditioning and reëxtinction series (sixth conditioning and extinction). The data from these six animals are given in Tables III and IV.

The mean Vincent-curves based upon the data given in Tables III and IV for conditioning and extinction through the third reconditioning and reëxtinction series are presented in Fig. 5.[13] Since beyond the third reconditioning and re-extinction series there are records from only two dogs, no average curves for the fourth and fifth reconditioning and reëxtinction are given. However, inspection of the data given in the tables shows that the two processes were continued with these two animals (Nos. 1 and 2) until either conditioning or extinction could be initiated with a single trial.

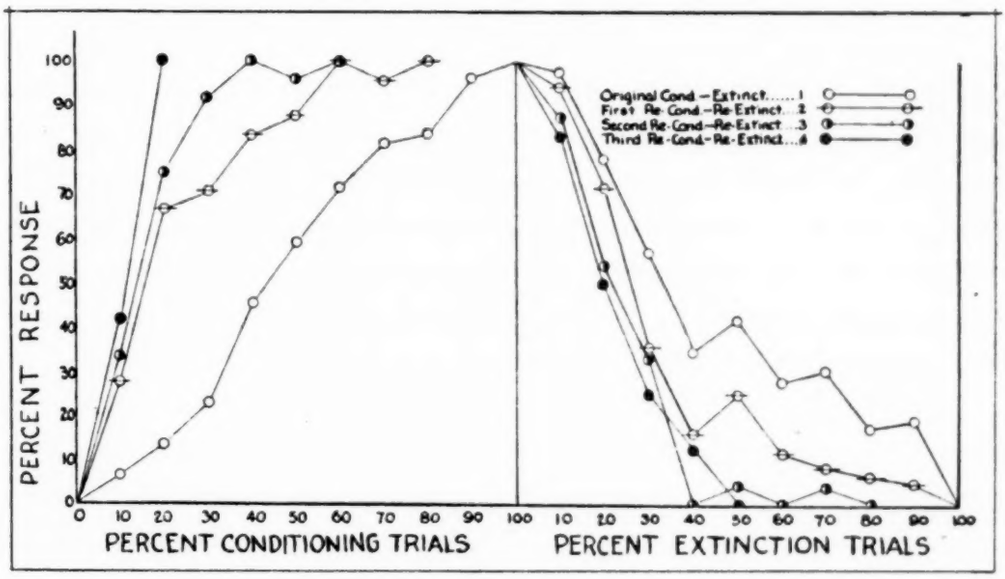

FIG. 5. Vincent-Curves of repeatedly alternated conditioning and extinction in six spinal dogs. The curves represent the data through the third reconditioning and reëxtinction series.

It is obvious upon inspection of the curves in Fig. 5 that there is a fundamental similarity in each corresponding pair of curves for conditioning and extinction, *i.e.*, the conditioning and extinction curves for the same series are approximately identical when superposed. This is further evidence for the concept advanced by Culler (**2**, p. 152) to the effect that extinction is fundamentally a conditioning process in its own right and 'may properly be called negative or inverse conditioning.'

E. The Relation of Conditioning to Reconditioning and Extinction to Reëxtinction.—Since in the conditioning process the

[13] See footnote 3, *op. cit.*, 1939.

CS is always reinforced by the *UCS* and in the extinction process the *CS* is never reinforced by *UCS*, it is possible for the preparation to differentiate between conditioning and extinction from the first trial. That the preparation becomes increasingly proficient at distinguishing between conditioning and extinction processes is illustrated by the conditioning and extinction curves in Fig. 5. Both conditioning and extinction move more rapidly to completion with each repetition of the processes (Shurrager and Culler, **12**, p. 186). Records from the two preparations in which conditioning and extinction were alternated six times (Tables III and IV) show that Animals Nos. 1 and 2 differentiated between conditioning and extinction after the first trials of the fifth and sixth conditioning series and thereafter reacted to the *CS* with either 100 percent response or 100 percent absence of response. Evidently there is retained in the delimited segment of the spinal preparation (presumably at the synapse) an effect which is cumulative, positive, and persistent as a result of the conditioning and extinction processes.

Discussion of Results.[14]—Neuro-physiologists have long been studying the ways and means (chemical and electric) by which the impulse traverses the synapses of reflex paths which are already established. The neuro-psychologist, while confronted with the same problems as the physiologist, has in addition been concerned with the mechanisms by which new paths are alternately made functional (conditioned) and non-functional (extinguished). Specifically, the neurological problems of conditioning and extinction are: (1) what is the *locus* of the central nervous mechanisms which are necessary for conditioning and extinction to proceed; (2) what is the *nature* of the *CR* thereby created; (3) what is the *course* of the conditioning and extinction curves; (4) what *relation* have conditioning and extinction to each other; and (5) what are the

[14] The concept of spinal conditioning, as presented here, is not discussed in relation to the Pflüger-Lotze controversy which for years belabored the question: does the behavior of the spinal animal give evidence of the existence of consciousness or show the marks of purposiveness (Fearing, **6**, p. 165)? The material here offered for analysis and interpretation merely exhibits certain phenomena which appear under controlled experimental conditions within the isolated spinal cord of the dog, whatever be the relation of these phenomena to consciousness or mind.

central nervous *mechanisms* which produce the conditioning and extinction? These five questions are discussed below in the light of spinal conditioning results.

A. Central Levels of Conditioning.—Heretofore, it has been assumed that higher brain levels are necessary for conditioning and subsequently for extinction to occur. Experimental evidence from the decorticate dog (Culler and Mettler, **3**, pp. 299 *ff*) led to the postulate that cortex is responsible for 'specific' conditioning, but that conditioning of a 'diffuse' type can be established in the decorticate or thalamic dog with as little difficulty as that encountered in the normal animal. The data presented here (Figs. 3, 4, and 5 and Tables I, II, III, and IV) constitute adequate evidence that there exist functional mechanisms in the isolated spinal preparation which are capable of initiating phenomena comparable to, and fulfilling all the usual criteria for, conditioning and extinction in the intact animal.

B. Differences between Intact and Isolated Spinal Conditioned Responses.—The main differences between the *CR* of the intact animal and the *CR* of the spinal preparation concern the extent and duration of the *CR* rather than the response mechanisms. That is, with the intact animal the conditioning first appears as a general (diffuse) response and then proceeds gradually to become localized (specific) in particular muscle groups. In the isolated spinal preparation, on the other hand, the *CR* makes its appearance upon a limited group of muscle fibers in the M. S–T and then, as the conditioning is continued, may spread to adjacent muscle fiber groups. In short, the *CR* in the normal and the spinal animal seem to be inversely related. It may be, however, that the diffuse response of the intact animal merely submerges a specific conditioning which is similar to that observed in the spinal preparation. However that may be, we are here concerned only to show that the criteria of conditioning which are derived from the intact animal apply also to the spinal preparation, whatever the mechanisms may be.

C. Conditioned Response Mechanisms as Synaptic Processes.—Such descriptive terms as equipotentiality, vicarious

function, mass action (Lashley, **9**), generalization, irradiation, induction, inhibition and disinhibition (Pavlov, **10**) have heretofore been freely applied at cortical and thalamic levels; whereas the spinal preparation has been considered in terms of direct point-for-point localization of function along established and innate fiber-paths within the reflex arc (**1**, p. 1). These spinal functions involve excitation, inhibition, summation, and facilitation within specific reflex mechanisms. Since observable activity in the spinal preparation appears as contraction of specific muscle fibers and since specific nerve pathways are known to be involved, spinal conditioning must be discussed in terms of synaptic processes.

In discussing the synaptic processes in conditioning, which depend upon the *CR* (muscle response) for their expression, we must consider a few salient points. The *UCS* initiates a *ces* (central excitatory state) which is able to raise the motoneurones above the limen of excitation and thus effect maximal reflex contractions (*UCR*) of the M. S–T, whereas the *CS* arouses a different central excitatory state (*CS ces*) which is at first insufficient to effect even a diminutive reflex twitch. Only after repeatedly combining these two peripherally initiated central excitatory states in the conditioning process will the *CS ces* alone be able to arouse a few of the more conditionable motoneurones. The combination of central excitatory states obviously either establishes a new path in the central nervous system or strengthens (functionalizes) a subliminal synaptic state which already exists between the *CS ces* and the motoneurones involved in the *CR*. Functionalization of an already existing synaptic path seems the better hypothesis, since there is little or no evidence that actual axonic growth occurs rapidly within the nervous system due to peripheral stimulation. It would seem improbable that interaction of *CS ces* and *UCS ces* would effect a functional synaptic juncture unless a structural (but non-functional) juncture were already present. Also, since conditioning and extinction can be effected with increasing ease with each repetition of the processes in the same preparation, there is little doubt that

such synaptic junctures can be relatively permanent and still exist non-functionally.[15]

The fact that this new type of connection has been observed to persist after being established for as much as nine hours and thereafter to be readily extinguished shows that a stable relationship has been established and now exists between the *CS* and the established *CR*. Such a stable relationship (association) presupposes a functionalizing mechanism which may involve a chemical steady state, a bio-electric steady state, or some combination thereof. That such a functional state comes to exist at all probably demands changes in metabolism of the cells involved, possibly only at the synapses traversed. The new functional state is cumulative and though it may involve the whole neurone, must certainly involve the synapses in the path of the *CS ces*. The motoneurone synapses would most likely furnish a common path and locus upon which *CS ces* and *UCS ces* might both impinge and at which the suspected functionalization might occur.

Upon continuing the conditioning process, we observe that the *CR* progresses from a localized twitch near the insertion of M. S–T to a more extensive contraction of adjacent muscle fibers. This 'spread' of the *CR* to include more and more fibers suggests (1) that there is a continual spread of the *central* conditioning process within the cord involving more and more motoneurones, and (2) that the ability of the synapses to develop and maintain the 'steady state' varies from one motoneurone to another. The spread of the central conditioning process is responsible for the observed spread of the *CR*. The central conditioning probably takes place as a bioelectric or chemical relation across the synapses at the motoneurones. As a result of cumulative interaction between the central excitatory states initiated from tail and paw respectively, the synaptic central conditioned state eventually reaches a level at which it is possible for the *CS* impulses to traverse the newly functional synapse and effect the *CR* (re-

[15] The theory here advanced, that during extinction relatively permanent synaptic junctures become non-functional, is in accord with the concept of extinction advanced by Finch and Culler (7, p. 660) to the effect that extinction involves loss of 'incentive,' even though the 'pattern' is unimpaired.

flex twitch). The *CR* may thus involve few or many motor units.

D. A Measure of the Central Conditioned and Central Extinguished Synaptic States.—To secure a measure of central conditioning is essentially to measure the rate of accumulation of the synaptic functionalization which makes the *CR* possible. Data secured from six dogs (Tables III and IV) show a supraliminal portion of the increase in synaptic state (possibly at the motoneurones) as the cumulation becomes great enough to permit the *CS ces* to activate the motor units and initiate responses of the muscle fibers. These data indicate that the synaptic residue increases with each successive reconditioning until eventually conditioning and extinction can both be effected in a single trial (Table III: Animal No. 1, 4th, 5th, 6th series; Animal No. 2, 4th, 5th, 6th series; Animal No. 3, 4th series; Animal No. 4, 3rd series; Animal No. 5, 3rd, 4th series; Animal No. 6, 4th series; Table IV: Animal No. 1, 6th series; Animal No. 2, 4th, 5th, 6th series). These data, as expressed by the parameters of the reconditioning and reextinction curves (Fig. 5), exhibit the rate of cumulation of the central conditioned state and the central extinguished state as well; as is proved by the fact that, during the third, fourth, and fifth reconditioning and reëxtinction, either reconditioning or reëxtinction could be initiated by a single trial and the further fact that both could thereafter be maintained at 100 percent for nineteen successive trials. It follows that the central conditioned and central extinguished synaptic states were cumulated to a maximum, since obviously reconditioning and reëxtinction cannot be effected in less than a single trial.

E. The Relation of Conditioning and Extinction to their Central Synaptic States.—Since the original conditioning and extinction curves are essentially superposable (Fig. 4), and since the central conditioned and central extinguished states are similar, positively cumulated, synaptic states (Fig. 5), it is suggested that conditioning and extinction involve similar, if not identical, synaptic mechanisms. These synaptic mechanisms are mutually inhibitive with respect to the synaptic transmission of the *CS* impulses in effecting the *CR*.

F. Summary of the Discussion.—The above analysis of spinal conditioning data has centered about five questions. These questions and the tentative answers suggested are summarized below:

(1) What are the *loci* of conditioning and extinction?
Conditioning and extinction are not restricted to cortical and thalamic levels but are general properties of central nervous tissue. The synapses of the motoneurones are suggested as loci of both conditioning and extinction in the spinal dog.

(2) What is the *nature* of *CR?*
The *CR* in the spinal animal differs in magnitude and in its developmental course from the *CR* of either the intact or thalamic animal. The relationships among these three types of *CR* (spinal, thalamic, and intact) are still obscure.

(3) What is the *course* of the conditioning and extinction curves?
Mean Vincent-curves for the spinal conditioning and extinction data presented in this paper are plotted and shown to be superposable.

(4) What is the *relation* between conditioning and extinction?
There is a direct relation between the number of trials required to condition and subsequently to extinguish the response in any given preparation.

(5) What are the central nervous *mechanisms* which produce the conditioning and extinction?
Both conditioning and extinction are shown to result from similar, positively cumulated, central synaptic states. This suggests similar synaptic mechanisms.

Summary

1. Phenomena which meet the criteria of motor conditioning and extinction are shown to occur in the spinal dog. When mechanical or electric stimulation of the tail is combined with shock to the left hind-paw, the flexor muscle, M. semi-tendinosus, which at first contracts only to paw-shock, comes to respond when the tail alone is stimulated.

2. The curve of conditioning and curve of extinction are shown to be superposable when each is based in the Vincent manner upon the percentage of total trials from zero to one hundred percent score. The unit in conditioning is *Presence of CR*, in extinction *Absence of CR*.

3. Curves of reconditioning and reëxtinction show that both conditioning and extinction move more rapidly from zero to one hundred percent score with each repetition of the processes in the same preparation until the *CR* can be established or abolished in a single trial.

4. The mechanisms of conditioning and extinction thus appear to implicate similar, if not identical, synaptic processes which are mutually inhibitive with respect to the transmission of *CS* impulses in effecting the *CR*.

5. Instead of the generalized functions commonly invoked to explain learning in the intact or thalamic animal, specific synaptic states are suggested as the responsible mechanisms for conditioning and extinction in the spinal preparation.

6. Conditioning in the cord begins with a small group of fibers (presumably the largest and fastest) and then spreads to adjacent (presumably smaller and slower) fiber-groups. With the intact animal motor conditioning begins with widespread activity and then gradually converges upon a single act or muscle-group. The participation of neuro-motor units in one case (spinal) is a diffusive progression (from less to more extensive) and in the other (intact) a focal progression (from more to less).

7. The peripheral motor *CR* is distinguished from the central (synaptic) conditioned state upon which it depends. The central conditioning process which functionalizes the synapse and which may exist in subliminal or supraliminal degree presumably involves a prerequisite set of conditions (whether bio-chemical, bio-electric, or both). It is upon the functional magnitude of the central conditioned synaptic state resulting from the functionalization of the synapses that the peripheral *CR* depends.

8. The motoneurone synapses are proposed as loci for the cumulated synaptic state resulting from the central conditioning process.

9. A supraliminal portion of the central conditioned and central extinguished synaptic states is measured and recorded as their states approach the limit of stability set by the criterion and by the conditioning and extinction techniques.

10. Control experiments failed to induce backward conditioning in the spinal preparation.

11. Evidence from severing spinal roots indicates that the central conditioned state is located at the level of the spinal cord at which the conditioned muscle response is innervated. Not *all* roots innervating the conditioned muscle are necessary for the conditioned response to persist.

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THE SPAN OF VISUAL DISCRIMINATION AS A FUNCTION OF TIME AND INTENSITY OF STIMULATION

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Introduction

The psychological literature contains many experimental studies on the span of visual discrimination which have been interpreted by their authors as studies of the span either of attention or of apprehension. These interpretative labels and their accompanying discussions indicate clearly that the problem was viewed as one whose investigation would illuminate such phases of mental life as the following: How many objects can be grasped in a single moment of consciousness? How many levels of clearness are there? What is the difference between attention, cognition, and apprehension? How does the span of attention vary with the instructions given the subject, with the character of the material used, and with the age and training of the subject?

So far as we can discover no investigator has viewed the experiment as one on visually controlled behavior and one therefore whose results should be related to the known mechanisms of vision if a satisfactory explanation of the results is to be forthcoming. Exposure times as a rule have been chosen which are too short to permit shifts of fixation on the assumption, apparently, that only so would a single moment of consciousness be involved. Although some investigators have compared the effects of different exposure times upon span, under otherwise constant conditions, no systematic study of the problem has been made. Dallenbach (**2**), in an incidental part of one study, approaches this most nearly when he used exposure times of .04, .08, .12, .16, .20, and .24 secs. Forty cards, holding 5 or 6 colored rectangles each, served as the stimuli. The subjects named and described what they

had seen. The results show that for each of three subjects there was a small but constant increase in the average number of colors cognized as the exposure time increased.

As with exposure time, so with intensity; only one systematic study is available although Fernberger (3), for example, varied intensity by using black dots against either a gray or a white background with an exposure time of 0.10 secs. and secured essentially negative results which Cooper (1) later confirmed. Schlegel (9) has presented the only thorough study in an experiment using a constant exposure time of 0.112 secs. and 16 different degrees of intensity of transmitted light. Intensity thresholds for the discrimination of one to four bright dots on a dark background were determined. The results clearly indicate that intensity of stimulation is a factor in determining the number of dots discriminated.

The span of discrimination with visual stimulation is determined essentially by the subject's ability to identify the number of objects (dots, words, figures) presented. As characteristically investigated the intensity of stimulation has been kept constant and approximately optimal. The duration of stimulation has also been constant at some small fraction of a second (about 100 ms.) which would preclude 'shifts of attention' and identifying responses during the exposure of the stimulus. Presumably nothing but theoretical bias has stood in the way of a systematic analysis of the problem and obscured the fact that the span of visual discrimination is a problem in visual discriminative behavior where time and intensity have well known roles. If the subject's ability to identify the number of dots presented is at issue, intensive and durational limens can be secured either by keeping the number of dots constant and determining the limens or by determining the number of dots that can be identified 50 percent of the time at various durations and intensities. The latter is the method used in the present investigation.[1]

An impressive series of experiments has shown that the Bunsen-Roscoe law ($I \cdot t = C$) holds within limits for many visually determined processes, including the following: the

[1] We are greatly indebted to Professor Clarence H. Graham of Brown University for his expert advice and guidance in the visual aspects of the problem.

orienting responses of plants (Blaauw) and animals (Loeb and Northrop), nerve impulses from the eel's eye (Adrian and Matthews), the initial and maximum frequency of nerve impulses from single visual receptors in the eye of Limulus (Hartline), and human visual discrimination (McDougall, Blondel and Rey, Piéron, Graham and Margaria, Karn, Graham and Cook). In each case some response, or characteristic of response, is taken as the constant and the product of the time and intensity of stimulation required to produce it is determined. In the experiment to be reported in the present paper, the number of dots correctly identified 50 percent of the time is taken as the Constant. The results show that within limits $I \cdot t = C$ for the span of visual discrimination, a fact which enables us to reinterpret the 'span of attention' experiment as well as to relate the phenomenon to well established principles of visually controlled behavior.

Apparatus and Method

The present experiment was carried out over a period of two years using the same two subjects throughout the work.[2] Inasmuch as most of the results herein reported are drawn from the second year's work, any long term practice effects are presumably absent. Improvement of response during any single session, particularly after a lapse of time without experimentation, was reduced if not eliminated by beginning each session with a practice series.

During the experiment the subject sat in a dark cubicle at a distance of 11 feet from the stimulus field which he viewed, with both eyes, through a stereoscopic hood (minus the lenses) arranged as a head rest. The stimulus field was a circular opal glass plate of $1\frac{3}{4}$ in. radius, 1.5° visual angle. The plate was set in the wall which separated the subject's cubicle from the apparatus room. A white painted circle around the plate was illuminated from the sides by faint lights, hidden from the subject's direct vision, and served to outline the stimulus plate between exposures. The subject was instructed as follows:

"The object of this experiment is to determine how many dots you can see during a very brief exposure time. You are asked to report immediately after each exposure the number of dots you saw. Be sure of your report; do not guess. The report 'I do not know' is allowed. Sometimes a great many dots will appear; report only the number that you have seen.

"At the ready signal fixate your eyes on the center of the exposure field outlined by the white circle. Approximately two seconds after I say 'now' the stimulus will be given. *Remember to keep your eyes on the center of the field and report only the number of dots you are certain you see.*"

With the highest intensities of light at the longer durations, after images of the stimulus area were occasionally reported; but in no case did the subject secure after

[2] The authors owe a great debt of thanks to Miss Faith Allen and Mr. Dexter Hyland for their painstaking and coöperative work during the present investigation.

images of the dots themselves. At the longer durations (0.6 sec. and above) subject *A* reported more promptly than did subject *H* who tended to estimate the number of dots from memory. The results, however, indicate no particular difference between the two subjects.

A stimulus plate was made of two layers of clear glass between which was a thin sheet of translucent tracing paper on which the dot or dots were placed in black India ink. Each dot was 0.125 in in diameter, subtending a visual angle of 3.32′. Stimulus plates contained from 0–16 dots. Five different patterns were made on five different plates for 1, 2, 3, 4, etc., dots. A zero dot plate was also included. Two different systems of dot arrangement were used. During the first year of experimentation, the system was as follows: The required number of dots for a given plate were placed irregularly at distances of 0.5, 0.75, or 1.125 ins. from the center of the plate. No two dots were closer to each other than 0.125, the diameter of a dot. This system of constructing the plates did not keep acuity constant in that the distance between dots varied, but it did serve to decrease the direct suggestion of increasing numbers of dots which would result from an increasing area of contiguous ones. During the second year of experimentation, the single dot was in the center of its plate (one plate only being used) and where more than one dot was involved the distance between dots was constant at 0.25 in. This distance subtended a visual angle of 6.6′. With the two series of stimulus plates the total areas on which dots occurred subtended visual angles of 58′ and 42′ respectively, as contrasted with the fovea's 2–2.5° of rod free area. With both series of plates, the dots were arranged in irregular patterns. When the plates were used in the experiment they were placed in a holder flush with the opal glass of the stimulus area and between that glass and the light source. An exposure thus presented the subject with a field, illuminated at the determined intensity, on which dots darker than the field might be seen. The contrast between the field and the dots decreased as the field intensity decreased until no dots were visible in the field.

The light source, which was placed in the experimenter's room with the rest of the apparatus now to be described, including the above mentioned stimulus plate holder, was a 500-watt Mazda projection bulb. This was placed in an asbestos lined box and run at 110 v. direct current regulated by a rheostat and measured with a voltmeter located on the experimental table. The light from the bulb passed through two convex lenses and was focused on a metal slit .125 in. wide. Beyond the slit was a holder in which Wratten neutral tint filters or a wedge and balancing wedge could be placed for the control of light intensity. Measures of the full intensity of the light as it passed through the stimulus plate containing no dots were made from time to time from the subject's room with a Macbeth Illuminometer. Lower intensities were then calculated from the transmission values of the filter devices. Between the filter and the stimulus plate, all stray light was excluded by a cardboard tube.

For regulating the length of exposure time various devices now to be described were placed in the path of the light beam and as near the metal slit as possible. In order to secure exposures of 4, 8, 16, 32, and 75 ms. use was made of a synchronous motor (81 r.p.m.) carrying an aluminum disc 30 ins in diameter. Open sectors in the disc allowed the light to pass to the filters for the desired lengths of time. During any one session with the above time intervals, the motor ran constantly and a noiseless hand-operated shutter was used to allow the light to pass or not to pass through the disc opening. For exposures of 150, 300 and 600 ms., another synchronous motor (60 r.p.m.) carrying a light weight disc with a variable aperture was used. This device, the one used by Graham and Cook (4) for longer exposures, was started and

stopped for each stimulus exposure. For exposures of 1, 2, and 4 secs. a special device was constructed for us by Dr. Lorrin A. Riggs[3] which gave a relatively sharp onset and termination of the light. This was accomplished by having two screens moved, one out of the light path and the other into the path, by means of cams attached to a synchronous motor of 2 r.p.m.

In determining the actual exposure times used, the following methods were employed: (1) For 4, 8, 16, 32, 75 ms. an adjustable sector was cut from the aluminum disc to give the exposure times in terms of the speed of the motor. The actual exposures at 16 and 75 ms. were then photographed and the photographs measured under magnification. No error was detected in the 75 ms. exposure; but there was an uncertainty of 1 ms. in the 16 ms. exposure due to the size of the photograph. The 4, 8, and 32 ms. exposures were assumed to be correct as a result of the care in cutting the sectors in the disc. As nearly as could be determined the onset and termination of the light was instantaneous in the photographs. It is probable, however, that this was not the case at 4 and 8 ms. because the sector openings were but 4 and 8 times the diameter of the optical slit source. (2) The 150, 300 and 600 ms. exposures were also first determined by sector openings in the rotated disc in terms of the motor speed. The 150 ms. interval was then photographed and the sector opening adjusted to a final value of 150 ms. as photographically determined. The same procedure was followed for 600 ms., but the 300 ms. exposure was determined solely from the sector opening. With 150 and 600 ms., and presumably with 300 ms., about 7 ms. were required for the onset and again for the termination of the light. (3) For exposures of 1, 2 and 4 secs. the initial determination was again in terms of extent of sector opening. Adjustments were then made on the basis of photographic records until the error was less than 1 percent. With these exposures the onset and termination of the light each required about 7 ms.

In beginning the work of any one hour experimental session a practice series of discriminations was used to adjust the subject to the task and to occupy some 2–5 mins. of time where partial dark adaptation was desired at the lower intensities of stimulation. (The dot area of the stimulus plate subtended a visual angle well within that of the fovea, and dark adaptation of the fovea is essentially complete after 2 mins.) Since the dot stimuli were presented at a uniform rate, the degree of adaptation of the fovea was presumably reasonably constant for any one stimulus intensity although adaptation in the rod areas of the retina continued to progress during most of the session.

Experiments were conducted where exposure time and intensities were employed in a random order as well as where exposure times were used from short to long and intensities in the order from low to high. No differences in results by the two methods were secured. At any one experimental session the plan was to present a varied series of stimulus plates including those with a number of dots which could be reported correctly 100 percent of the time and extending to those which could never be correctly reported at the intensity and exposure time employed. (In practice it was not always feasible to reach these limits of 100 and 0 percents.) Each number of dots within the range utilized was presented a minimum of 30 times at each intensity and duration as a basis for the determination of the limens. This means that each subject made a minimum total of 90 reports at the lowest intensity for each duration where the

[3] Assistant professor of psychology at the University of Vermont on leave of absence to serve as research associate at Brown University, 1938–39. Dr. Riggs also aided in the calibration of exposure times.

stimulus plates used contained 0, 1, and 2 dots and a maximum total that ran as high as 210–240 reports under other conditions where seven or eight different numbers of dots would be required to cover the range from approximately 100–0 percent correct responses. The complete determination of the limen for a given intensity and duration usually extended over 2–3 experimental sessions, so that each session involved the accumulation of data on two or more intensities at a given duration. The method of determining limens will be described in the following section.

Experimental Results

Table 1 shows the individual and average limens (number of dots correctly reported 50 percent of the time) for each of the durations and intensities employed in the second year of experimentation. Both time and intensity were varied over a range of 1–1000, if we exclude .013 ml. intensity which was just below the limen for dot discrimination even with 4 secs. exposure and which it was therefore impossible to use. This table gives the basic results of the present study, and a high degree of reliability is claimed for the measurements. This claim is supported by the close similarity in the results of the two subjects, by the subjects' long training, and by the general conditions under which the work was done. A general inspection of the table clearly reveals that the span of discrimination is a function of the time and intensity of stimulation.

Figures 1, 2, 3, and 4 are samples of the curves utilized in determining limens. These figures show the performance of Subject *A* in reporting numbers of dots at different intensities for durations of 4, 32, 300, and 1000 ms. Each point on the curves represents the percentage of correct identifications of the number of dots represented on the abscissa and is based on a minimum of 30 responses. The limens used to represent the span of discrimination for a given time and intensity were determined by noting the abscissa value at which 50 percent of the discriminations were correct. It is these values which are entered in Table 1 and on which the following treatment will be based.

Figure 5 is a graph of the average of the two subjects' limens plotted against log intensity for each of the durations from 4–4000 ms. Similar graphs have been plotted using not the 50 percent limen but the 80 percent and 20 percent values derived from curves like those of Figs. 1–4. Since there is

TABLE 1

LIMINAL NUMBER OF DOTS FOR DIFFERENT TIMES AND INTENSITIES, TWO SUBJECTS

I (ml.)	4 ms.			8 ms.			16 ms.			32 ms.			75 ms.			150 ms.			300 ms.			600 ms.			1.00 sec.			2.00 secs.			4.00 secs.		
	H	*A*	Ave.	*H*	*A*	Ave.	*H*	*A*	Ave.	*H*	*A*	Ave.	*H*	*A*	Ave.	*H*	*A*	Ave.	*H*	*A*	Ave.	*H*	*A*	Ave.	*H*	*A*	Ave.	*H*	*A*	Ave.	*H*	*A*	Ave.
13.33	7.4	8.1	7.7	8.0	8.3	8.1	—	—	—	6.6	7.4	7.0	8.6	7.7	8.1	—	—	—															
6.67	6.5	7.8	7.1	8.4	8.0	8.2	8.1	7.8	7.9	6.5	7.8	7.1	—	—	—	8.8	9.8	9.3															
3.33	4.8	7.3	6.0	8.1	7.9	8.0	8.4	7.8	8.1	7.5	8.0	7.7	—	—	—	—	—	—															
2.61	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15.5	13.2	14.3						
1.67	1.6	1.3	1.4	5.6	6.0	5.8	—	—	—	—	7.9	7.9	9.1	8.2	8.6	—	—	—	—	—	—	13.2	11.1	12.1	—	—	—						
1.33	.9	1	.9	3.5	2.8	3.1	6.2	7.3	6.7	7.3	8.2	7.7	—	—	—	10.1	8.3	9.2	9.8	10.0	9.9	—	—	—	—	—	—						
.667				.7	.7	.7	4.5	3.4	3.9	5.7	7.8	6.7	8.5	8.0	8.2	—	—	—	—	—	—	—	—	—	—	—	—						
.52							1.8	—	1.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—						
.333							.7	.7	.7	2.9	5.4	4.1	7.0	7.4	7.2	8.5	8.1	8.3	9.7	9.0	9.4	12.6	10.6	11.6	—	—	—						
.26										—	2.2	2.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—						
.167										.7	.7	.7	2.8	2.4	2.6	—	—	—	—	—	—	—	—	—	—	—	—						
.133										.7	—	.7	2.4	1.8	2.1	6.0	7.0	6.5	8.8	8.1	8.4	10.4	10.6	10.5	13.2	12.0	12.6						
.104													—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	16.6	14.9	15.7			
.067													.6	.6	.6	2.1	1.5	1.8	6.0	5.8	5.9	9.8	9.3	9.5	12.2	10.2	11.2	—	—	—			
.053																.1	1.1	1.0	—	—	—	—	—	—	9.0	10.3	9.6	12.6	12.6	12.6	15.6	16.1	15.8
.033																			1.3	1.2	1.2	2.5	2.3	2.4	—	7.3	7.3	—	—	—	—	—	—
.026																				.9	.9	—	—	—	1.8	3.3	2.5	3.6	3.3	3.5	3.2	4.2	3.7
.016																						.9	.9	.9	.8	.8	.8	.5	—	.5	—	—	—

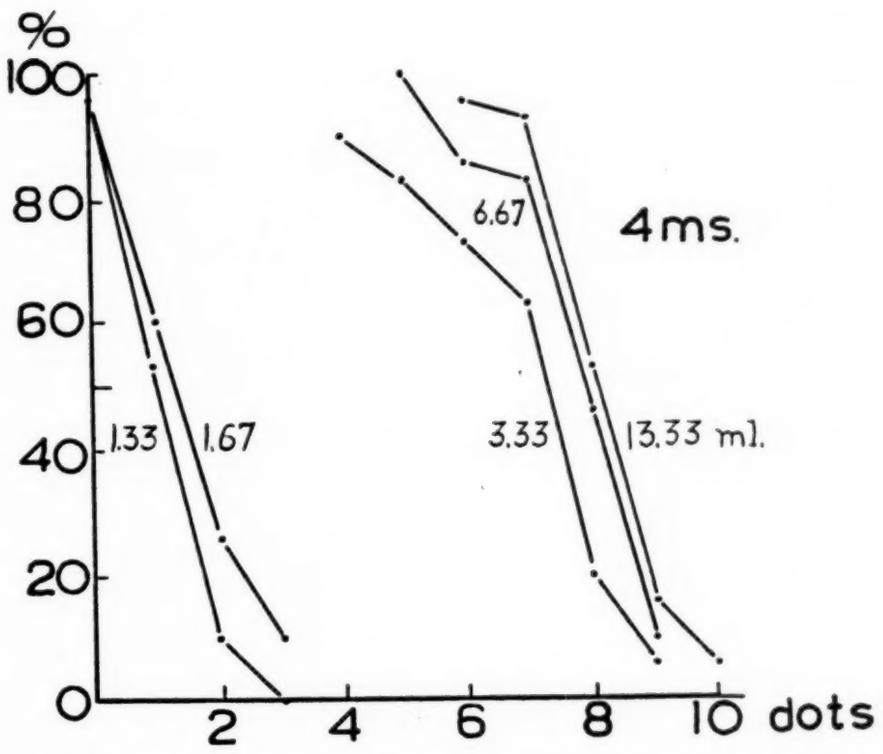

FIG. 1. Curves for Subject *A* showing the percentage of correct identifications of 2, 3, 4, 5, etc. dots at different intensities. Exposure time, 4 ms.

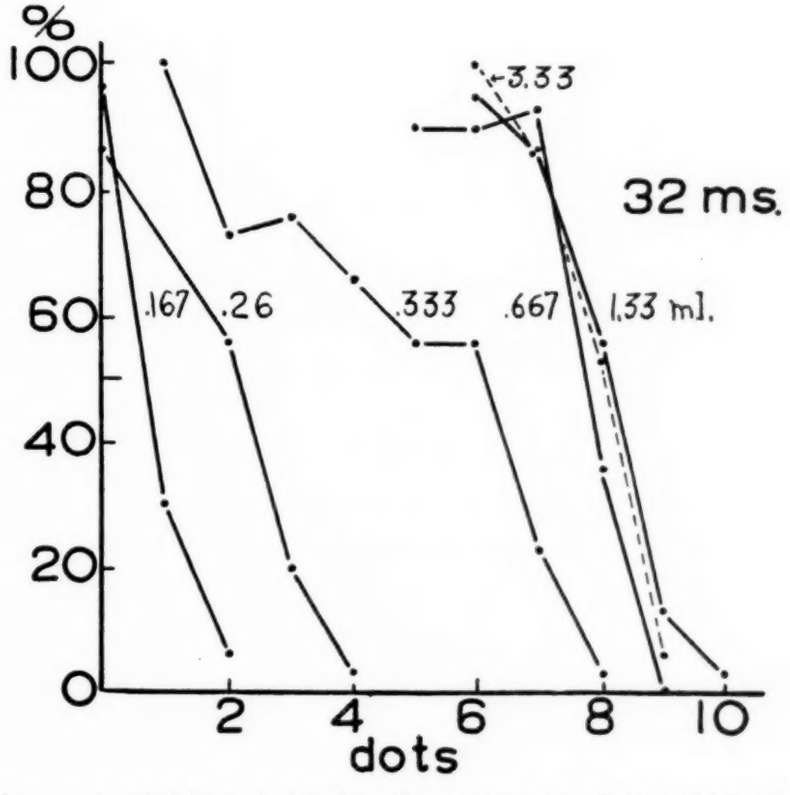

FIG. 2. Curves for Subject *A* showing the percentage of correct identifications of 2, 3, 4, 5, etc. dots at different intensities. Exposure time, 32 ms.

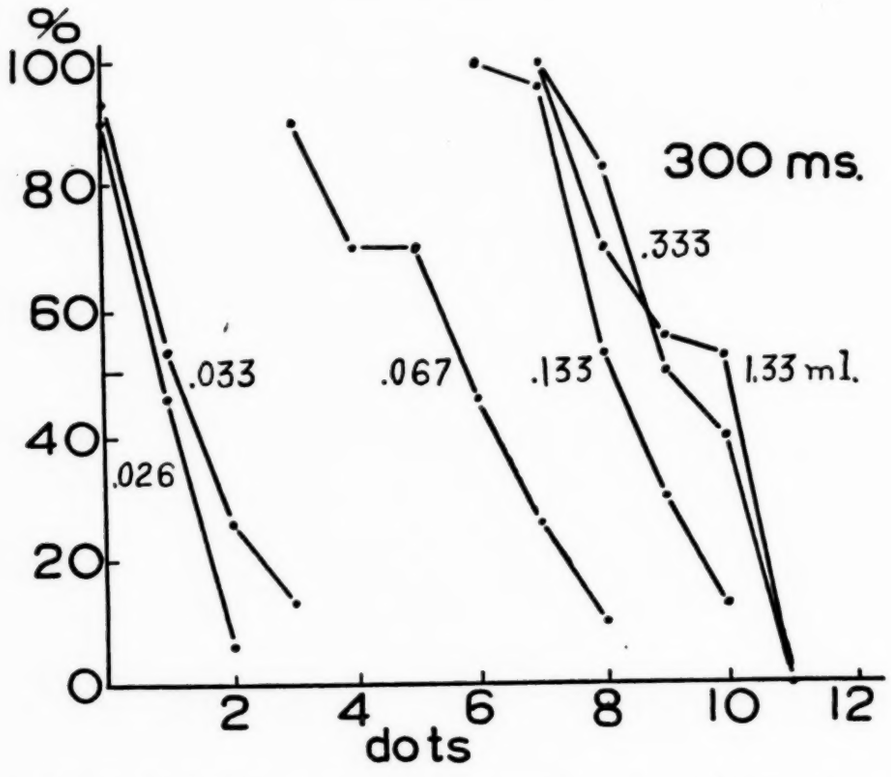

FIG. 3. Curves for Subject *A* showing the percentage of correct identifications of 2, 3, 4, 5, etc. dots at different intensities. Exposure time, 300 ms.

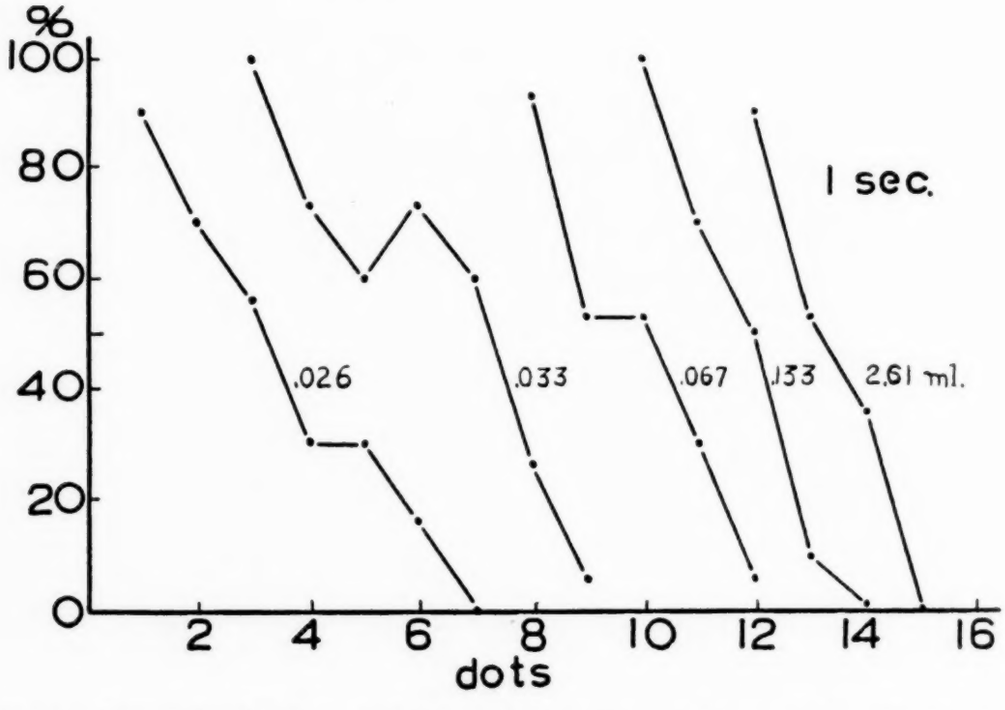

FIG. 4. Curves for Subject *A* showing the percentage of correct identifications of 2, 3, 4, 5, etc. dots at different intensities. Exposure time, 1 sec.

no essential difference revealed by such a choice of percentile value, our presentation will be limited to that of the conventional 50 percentile. Figure 5 reveals in a striking way some of the important relationships, between the span of dot dis-

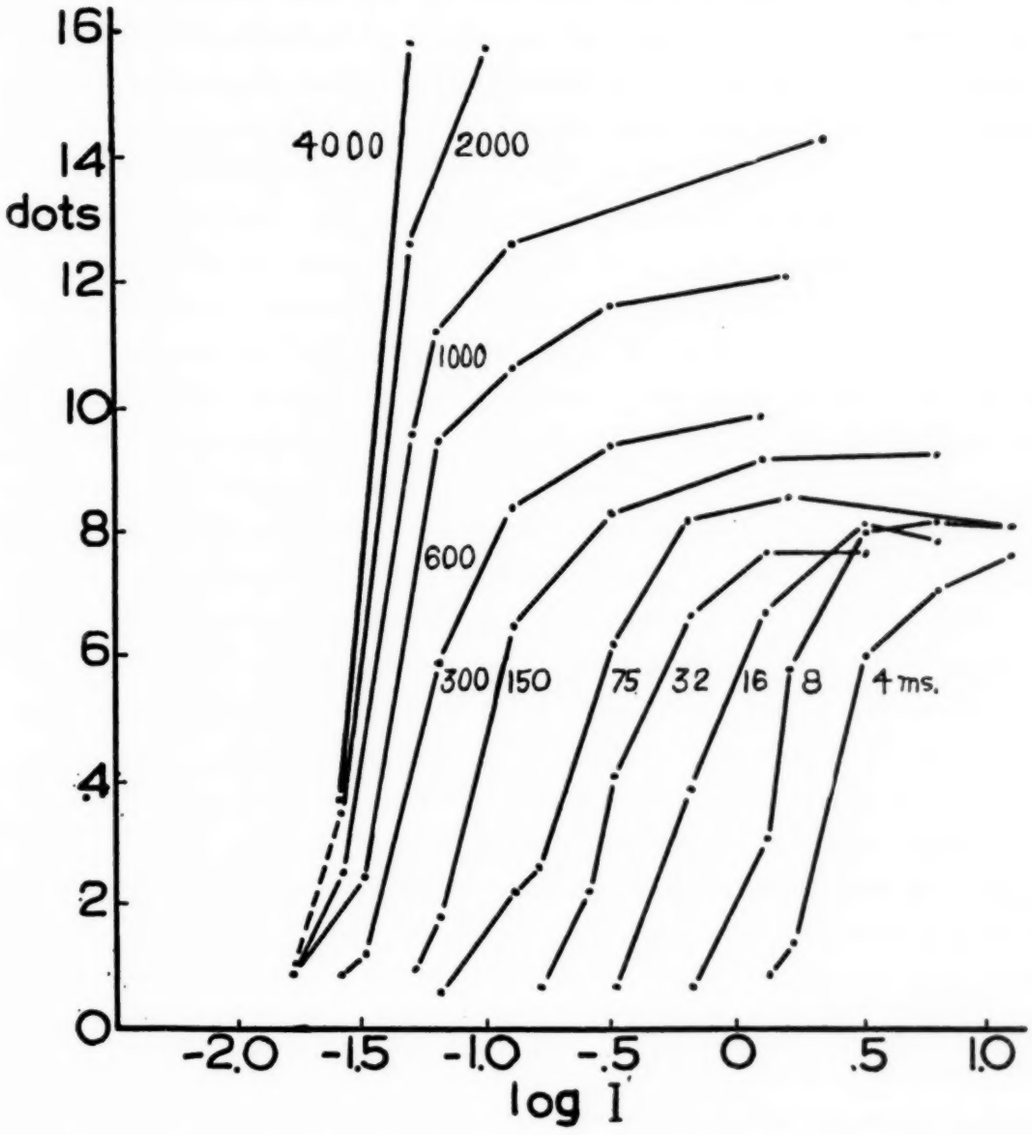

FIG. 5. Curves showing the number of dots correctly discriminated 50 percent of the time at different intensities and durations of exposure, based on two subjects during the second year's work.

crimination and the time and intensity of stimulation. (1) As the exposure time is increased the intensity required for the liminal discrimination of a given number of dots, 4 for example, decreases. Thus the curves for different durations are displaced progressively on the intensity axis. For limens of

1–7 dots and for durations from 4–300 ms., the amount of this displacement is relatively constant. (Attention should be called to the fact that the curves are drawn through experimentally determined points. It would have been entirely legitimate to have drawn best fitting curves, and such a procedure would have smoothed out the few irregularities found.) However, for durations of 600–4000 ms. the displacement for these limens becomes less and less indicating that even with great increases in duration the response still requires approximately the same intensity of stimulation. In other words intensity and not time is the chief determiner of the response. (2) The curve for each duration is sigmoid. As intensity increases there is first a relatively gradual increase in the number of dots reported, then a rapid increase, and finally a period of no increase in span even though higher intensities are used. (3) A third important point brought out by the figure concerns the maximum level of the span of discrimination under the various conditions. At exposures of 4, 8, 16, 32 and 75 ms. the maximum average limen does not vary from 8 dots by more than a fraction although the intensity required to reach this maximum decreases as the duration increases. Furthermore after the maximum span is reached further increases in intensity fail to raise the span. (The first year's experimentation brought out the fact that at still higher intensities than those used here, the span of discrimination actually decreases, the curves turning downward, probably due to visual glare.) At 75 ms. the maximum span is 8.2 dots at an intensity of 0.667 ml.; at 1.67 ml., it is 8.6 dots; and at 13.33 ml., it is 8.1 dots. Beyond 75 ms. the maximum span increases with the increase in exposure time. At 150 ms., the maximum span is approximately 9 dots; at 300 ms., 10 dots; and at 600 ms., 12 dots. At intervals of 1, 2, and 4 secs. maxima were not determined, but they probably are 14 dots for 1 sec. and somewhere above 16 dots for 2 and 4 secs.

During the first year of experimentation, using different stimulus plates of the type described above, the maximum span for 4 ms. was just under 7 dots; for 8–75 ms., seven dots; and for 150 and 300 ms., 8 dots. No longer durations were

employed. Although the maximal spans were thus lower with one type of stimulus than with the other, the curves relating time and intensity to span were of the same general character. Later in Fig. 7 we will present additional data from the first year's work.

Figures 6, 7, and 8 continue the analysis of the effects of time and intensity of stimulation on the span of discrimination by means of plots that reveal the extent to which the

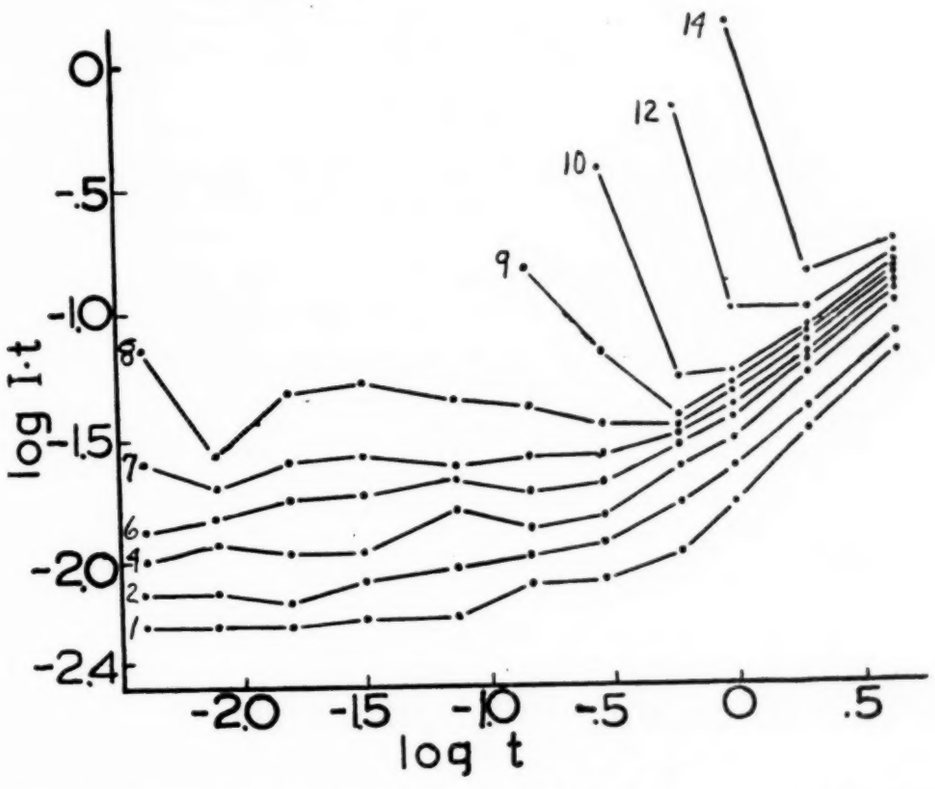

FIG. 6. Curves showing the total energy ($I \cdot t$) required for the liminal discrimination of 1, 2, 4, 6, 7, 8, 9, 10, 12, and 14 dots plotted against time. These curves are derived from those of Fig. 5.

Bunsen-Roscoe Law, $I \cdot t = C$, fits the data. This law states that a constant photolytic effect is determined by a constant amount of energy of stimulation which may be spread out over a shorter or longer duration of time. In the present experiment if we call the correct discrimination of 1, 2, or 3, etc., dots a constant effect, we can read from Fig. 5 the time and its associated intensity necessary for the production of such an effect. Thus the span of 4 dots at 4 ms. requires an intensity whose log is 0.4; at 8 ms., an intensity whose log is

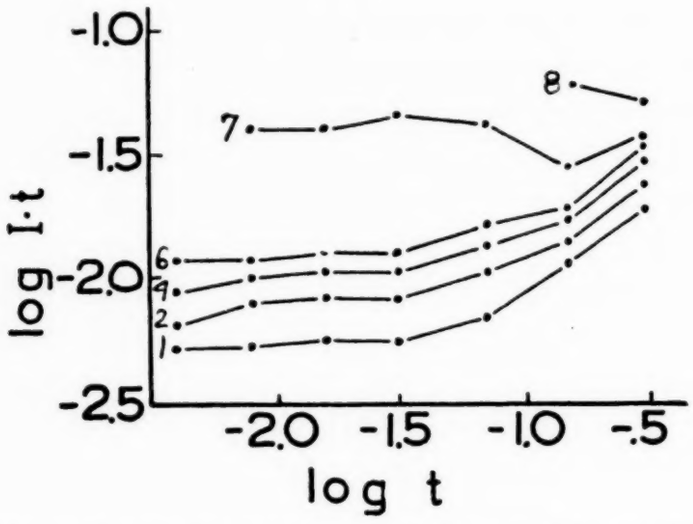

FIG. 7. Curves showing the total energy ($I \cdot t$) required for the liminal discrimination of 1, 2, 4, 6, 7, and 8 dots plotted against time, based on the first year's experimentation.

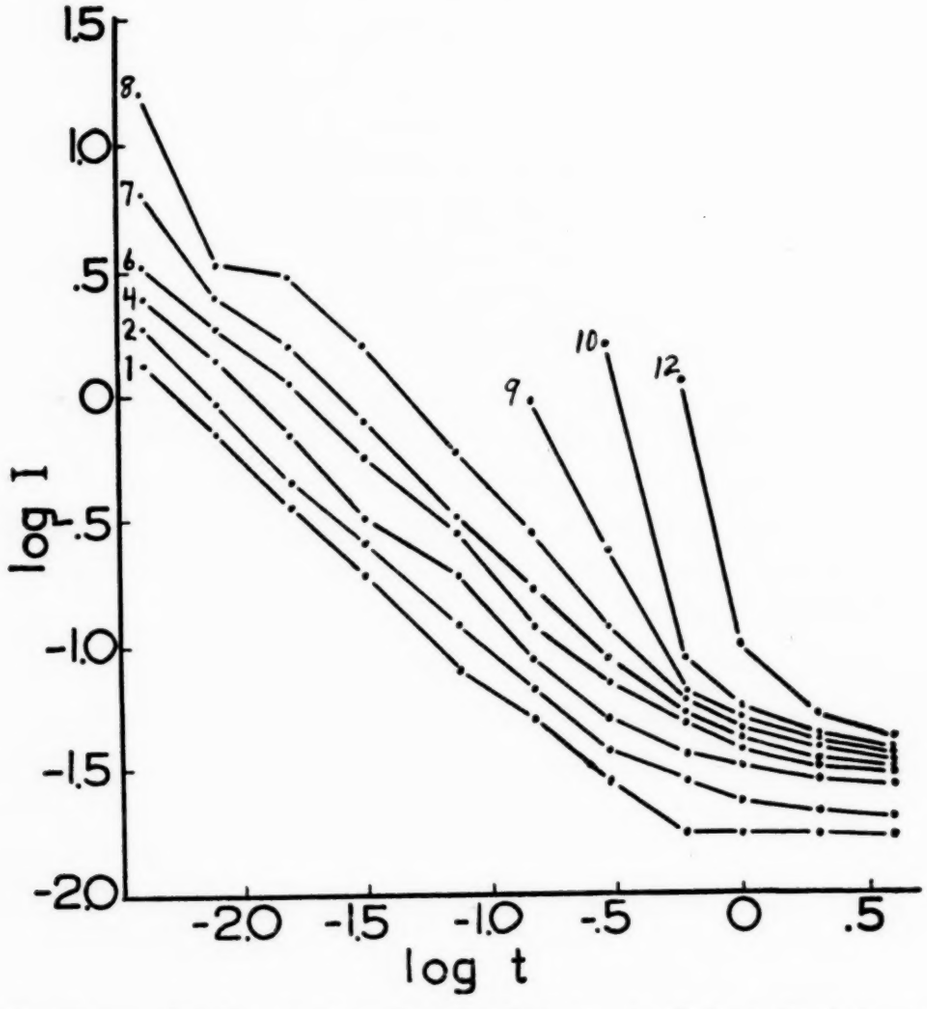

FIG. 8. Curves showing the intensity required for the liminal discrimination of 1, 2, 4, 6, 7, 8, 9, 10, and 12 dots plotted against time.

0.16; at 16 ms., an intensity whose log is 1.83; etc. Figure 6 plots log $I \cdot t$ against log t for spans of 1, 2, 4, 6, 7, 8, 9, 10, 12 and 14 dots. When plotted in this manner the relationship $I \cdot t = C$ is represented by a line with zero slope. A line of negative slope indicates that time is a more important factor than intensity while one of positive slope reveals intensity as more important than time. Where this positive slope is unity $I = C$, that is, increases in time no longer have an effect on the span. An inspection of Fig. 6 indicates that the Bunsen-Roscoe Law holds for spans of 1 and 2 dots for durations of 4–75 ms. and for spans of 3–7 dots for durations of 4–300 ms. after which the relationship gradually changes approximately to $I = C$. Practically no points vary more than 0.1 log unit from the line $I \cdot t = C$, which is the same order of fit found by Hartline for the time and intensity determination of an initial nerve impulse frequency of 40 per sec. in Limulus. For spans of 8 dots and over, time is a more important factor than intensity (negative slope) until durations of 0.6–2.0 are reached with various spans where at a critical point the relationship is reversed and intensity becomes the chief determining factor (positive slope).

The data of the first year of experimentation furnish the points for Fig. 7 which again plots log $I \cdot t$ against log t for spans of 1, 2, 4, 6, 7, and 8 dots. (The curves for 3 and 5 dots are omitted in the two figures solely for the sake of simplicity.) In this figure the points come from best fitting time curves for span vs. log I (comparable to Fig. 5), and consequently they show smaller deviations than is the case in Fig. 6. Here again the Bunsen-Roscoe Law holds for the shorter durations in the case of spans of 1–6 dots. In comparing Figs. 6 and 7 three points in particular need comment: (1) Since the maximum spans attained the first year were less than those of the second year (above, p. 171), spans of 7 and 8 dots are the largest that can be plotted. The curve for 7 dots is undoubtedly affected by the fact that the time curves (like those of Fig. 5) from which it is derived had begun to flatten out before the 7-dot value was reached. The fact remains that a relatively large amount of stimulus energy was

necessary to produce a span of 7 dots and that the amount of energy was approximately constant from 4–300 ms. On the basis of Fig. 6, it seems probable that for durations longer than 300 ms. the 7 and 8 dot curves of the present figure would have taken on positive slopes. The difference in maximal spans in the two sets of experiments derives from the different kinds of stimulus plates used rather than from different degrees of practice by the subjects. (2) It is to be noted that in both figures there is an increase in the total amount of stimulus energy with an increase in the number of dots discriminated. Graham and Margaria (**5**) and Karn (**8**) have shown that as the illuminated area increases there is a decrease both in the total amounts of energy ($I \cdot t$) and in the critical durations involved in the threshold discriminations for light flashes. In our experiments the greater the number of dots, the smaller the remaining illuminated area of the stimulus plate. Although our subjects were required to report number of dots rather than the presence or absence of a light flash, it seems clear that the ability to discriminate dark dots from a lighted field is a function of the area of the field which is illuminated for the given time and intensity. (3) The third point of comparison concerns the critical durations at which the curves take on definitely positive slopes. In Fig. 7 the critical duration is 32 ms. for 1–6 dots. In Fig. 6 the critical duration for even 1 dot is 75 ms., as it may also be said to be for 2 dots; but for 4, 6, and 7 dots, it is 300 ms. Our experimental situation is obviously complex from the explanatory point of view; but we suggest that the effect may well be due to the differences in sensitivity between the center and the periphery of the fovea. The stimulus plates used in securing the data for Fig. 6 had the dots concentrated in the center of the field whereas the dots on the plates for Fig. 7 were more widely scattered. Although both stimulus areas fell within the fovea, they differed in the degree to which they used the foveal center; and it is to be expected that the time-intensity relationships would differ under the two conditions.

Figure 8, based on the second year's experimentation, plots log I against log t for spans of 1, 2, 4, 6, 7, 8, 9, 10, and 12

dots. In this case a slope of unity indicates results in agreement with the Bunsen-Roscoe Law. A critical inspection will reveal the same characteristics of the dependence of span of discrimination on time and intensity that were shown in Fig. 6 and discussed above.

One type of qualitative result which we have obtained is interesting in connection with Schlegel's (**9**) experiment previously cited. Schlegel determined the intensity necessary for his subjects to see various numbers of dots at a constant exposure time. As one phase of the problem he compared the intensity necessary for a response of 3 (for example) when 3 dots were presented with the intensity necessary for seeing 3 when 4 dots were presented. Thus, for one subject, a relative intensity of 128 was necessary for the response of 3 when 3 dots were presented; but when 4 dots were exposed, the threshold for 3 decreased to a relative value of 105 as compared with 128. Similar results were obtained with other subjects and also with different responses.

Using data from the first year's experiment, we have selected the response of 5 for study, and have determined whether the report of 5 may be elicited by 6, 7, or 8 stimulus dots under conditions where it does not occur when only 5 dots are exposed. We have therefore selected for analysis a time-intensity series in which the reports on the 5-dot plates were of a low degree of accuracy. In the series considered, which included 310 reports on the 5-plates, all 5 dots were seen in only 24 percent of the trials. However, when 6 dots were presented at the same time and intensity 43 percent of the responses were of 5 or more. When 7 dots were exposed 64 percent of the reports were 5 or greater; and with 8 dots presented, the subject could see at least 5 in 85 percent of the trials. Correlated with an increase in the total number of objects presented there is a progressive increase in the probability that 5 dots can be reported. While these results are not strictly comparable to Schlegel's, they do tend to indicate that the ability to report 5 objects, for example, is conditioned by a number of factors and is not an absolute thing. At the

present time we are unable to give an adequate interpretation of this phenomenon.

Interpretative Comments

The most satisfactory explanation of the log $I \cdot t$ vs. log t curves has been given by Hartline (**6**). Where a given constant response, like the initial rate of nerve impulses, is determined by light stimulation, $I \cdot t$ may be expected to be constant up to that duration at which the sensory event is completed. Any increase in time beyond this critical duration is obviously uninfluential since the event in question is over. Beyond such a critical point intensity alone will be the determining factor. In Hartline's study the photochemical activity of the sense cell was the event in question. The indicator of this event was the nerve activity, the latent time of which was greater than the critical duration. In this experiment on the single sense cell of Limulus the critical duration was marked by a sharp break in the curve from zero slope to slope of unity. Experiments on the intact human eye have indicated that the transition between the two parts of the curve is gradual rather than sharp, a fact which led Hartline to suggest that a gradual transition between the two slopes is due primarily to the activity of many nerve cells. Graham and Margaria (**5**) and Karn (**8**) have tested this hypothesis in experiments using decreasing areas of stimulation in the human eye and have found that as the area gets smaller the transition between zero and unit slope becomes sharper.

Our curves in Figs. 6 and 7 of spans of 1–7 dots are so essentially like the curves derived from the study of admittedly strictly sensory functions that the rule of parsimony must lead us to utilize the same explanations since we too are dealing with a process that is a function of time and intensity of light stimulation. Even irregular groups of from 1–7 dots may be discriminated as a single event, *i.e.*, without counting, by such subjects as those used in the present experiment. On the contrary this is certainly not the case with 14, 13, 10, or even 9 irregularly placed dots. Here counting, *i.e.*, more than one event, is present. Our interpretation of the results

would therefore be as follows: The span of discrimination of from 1–7 dots, which is a single discriminatory event, is determined by the photochemical processes in the eye up to that duration at which the sensory contribution is complete. We have made no determinations of reaction times of the subjects under our experimental conditions which would give us data analogous to Hartline's above mentioned latent time of nerve response. However, since simple visual reaction times are of the order of 150–225 ms., the reaction times in our experiment would obviously be much greater than our critical durations which show when the strictly sensory contribution is complete. Beyond the critical duration, time becomes relatively less important until finally intensity is the chief determining factor.

It is a striking fact in Fig. 6 that the curves for 8 dots and over have initially negative slopes which become positive only at the higher exposure times. The construction of the graph is such that a negative slope indicates that time is a more important factor in determining span than is intensity. Since we are certain that the discrimination of a large number of dots, let us say 12, involves counting and therefore that time is an important factor, we are led to infer that even the span of 8 dots has taken us over the boundary of a single discriminatory event and into the counting area because its curve also has a negative slope. In spans of 8 dots and over we have not left the field of sensory determination of response as indicated by the role of the Bunsen-Roscoe Law, but we have obscured that role by dealing with more than one event at a time.

Summary and Conclusions

The effect of a thousand-fold variation in time and intensity of stimulation upon the span of visual discrimination for dark dots on a light field has been determined in a series of experiments using the same two subjects over a two year period. The durations of exposure were .004, .008, .016, .032, .075, .150, .300, .600, 1.0, 2.0, and 4.0 secs. The intensities varied from .013–13.33 ml., although not all were used with each duration.

The results indicate that as the duration of exposure is increased the intensity necessary for a liminal discrimination of a given number of dots decreases. At a given duration, as intensity increases, there is an increase in span first slow, and then rapid until finally a maximum span for that duration is reached. For durations of 4–75 ms., the maximum span is essentially 8 dots. At 150 ms., the maximum is 9 dots; at 300 ms., 10 dots; and at 600 ms., 12 dots. For durations of 2 and 4 secs. the span goes above 16 dots even at relatively low intensities.

Since the span of visual discrimination is a problem in visually controlled behavior, the results have been analyzed to see to what degree the Bunsen-Roscoe Law ($I \cdot t = C$) held. Calling the span a constant effect, it was found that the product of time and intensity required to produce this effect was constant for durations of 4–75 ms. for spans of 1 and 2 dots, and for durations of 4–300 ms. for spans of 3–7 dots. With longer durations, exposure time becomes progressively less important than intensity for spans of 7 dots or less. For spans of 8 and more dots, $I \cdot t$ is not a constant; but time is a more important factor than intensity until the long durations are reached where the relationship is reversed.

These results are interpreted to mean that where the span is a single discriminatory event (1–7 dots) as opposed to several such events, as in the necessary counting of more than 7 dots, the Bunsen-Roscoe Law holds up to that duration at which the sensory contribution is complete. Stating this in other words, we may say: the span of a single discriminative event may vary from 1–7 dots depending upon the intensity and duration of the stimulation; and up to the duration at which the sensory contribution is completed, a constant amount of sensory energy is required to produce the event. Beyond that critical duration, intensity is more important than time. The 'span of attention' thus resolves itself into a span of discrimination, a form of behavior which in the field of vision is controlled on the receptor side by time and intensity factors.

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THE FORGETTING OF 'CROWDED' AND 'ISOLATED' MATERIALS*

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A number of recent experiments have shown that so-called 'isolated' items in a list of material such as syllables or geometrical figures are remembered far better than are repeated or 'crowded' items. In the original experiments of von Restorff, single pairs of syllables and of numbers were included in a list of six pairs of geometrical figures (**14**). The material was learned and tested by the method of paired associates, and nearly three times as many correct recalls were recorded for the isolated pairs as for the crowded pairs. A rotation of the kinds of material tested within each constellation gave substantially the same results.

Subsequent experiments demonstrated that the factor of isolation, as opposed to crowding, is effective also in the case of recognition (**14, 8, 13**), with serial rather than paired associate learning (**11**), when items occurred not only within a single series but spaced in a succession of experiments lasting over a two-hour period (**11**), in tests of spontaneous rather than intentional recall (**8, 1**), and finally, in tests utilizing the beneficial effect of memory (of a previously clearly viewed item) upon tachistoscopic perception (**8**). The variety of these experiments is so great as to remove doubt that isolation is a factor having general significance for the problems of memory and learning.

There remains, however, some question as to the importance of isolation in the realm of retention proper. Quite apart from the importance of isolation for learning or for

* These experiments were conducted at Swarthmore College in the spring of 1939 during the first writer's tenure as Research Associate in Psychology.

recall, the fate of isolated 'traces' may be the same as that of crowded 'traces,' or their fates may be quite different.[1] A partial answer may be contained in a comparison of the forgetting curves for the two types of material. This paper presents such material.

The experiment was performed with a specific expectation concerning its outcome. This expectation was based on two independent lines of argument. First, it is possible to assume that isolation operates to make certain traces relatively more available for recall. Then, if retroactive inhibition is thought of as negative transfer, or as dependent upon some communication between the traces and interpolated processes, we are led to the same prediction: the more available the original trace, the greater will be the chance that associations will be formed which may be detrimental later, or, the greater the chance that interpolated processes will communicate with traces to the detriment of later recall. In either case, it follows that forgetting conceived as a generalized form of retroactive inhibition should be proportionately greater for the isolated items. To the extent to which isolation means simply availability, it should lead to good initial recall and rapid forgetting.[2]

A second argument follows from the assumption that the difficulty of crowded items is due to the presence of intra-serial inhibition. In serial learning, for example, Hull (**6**) has held that remote excitatory tendencies span successive items and that these must be inhibited before a list can be mastered. There is reason for supposing that these inhibitions disappear with time, to the advantage of later efforts at recall. The loss of inhibition thus may offset the decremental effects of forgetting. In cases where the degree of inhibition is very great due to the close spacing of practice trials (**4**, **5**), or the massing of large amounts of inhibitory material (**12**), the recovery may be so great that reminiscence results: more is recalled after a lapse of time than was recalled on an initial

[1] The results of experiments by I. Müller (**11**), in which the items of a series were spaced in time, suggests an interaction among traces. It is possible, however, to interpret her results in terms of some form of process-trace interaction.

[2] Koffka (**7**) also has suggested this line of reasoning.

test. But whatever may be the magnitude of this effect, it should always operate to slow up the process of forgetting.

Both lines of argument lead clearly to the same conclusion, namely, that isolated material should be forgotten relatively faster than crowded material. It should be noted that this conclusion refers only to the relative rates of forgetting and does not enable us to say what will be the final absolute level. It may be that since isolated material will have initially a far higher absolute level of recall, this superiority may be maintained for a long period even though the rate of forgetting is relatively more rapid.

Experiment I

We proposed to test the expectation discussed above by plotting forgetting curves for isolated and crowded materials. Several groups of *S*s learned lists containing two items of one kind of material (isolated) and six items of another kind (crowded). An immediate recall test was given in uniform manner to all groups, and an unexpected second recall test was given at various later times. In this way we can follow the course of retention for the two kinds of items, using but one unexpected recall for each experimental group.

Experimental Procedure

Specifically, our procedure was as follows: each group of *S*s was shown a series of eight 5″ x 8″ stimulus cards, at the rate of about 2 secs. per card. The series was exposed either two or three times, and an immediate recall test given by the method of reproduction. The stimulus materials are shown in Fig. 1.

*S*s were simply asked to observe the cards carefully, before the first exposure. Before the last exposure, however, they were warned that immediately at the end of the series they would be asked to reproduce the various items. This they did without regard to order or exact proportion of the stimulus items. This method was chosen because of its simplicity for use with naïve groups. *S*s were requested at the time of the immediate recall test not to discuss the experiment with anyone, and had no further contact with *E* until, at the chosen time, he returned without warning to ask for another reproduction.

*S*s for one set of experiments (see Table I) were high school students of the 10th and 11th grades (they were given three exposures of the cards). For the other experiments college students were used. They were recruited from elementary psychology and philosophy courses and were mostly freshmen and sophomores (two exposures of the cards).[3] Furthermore, for each of the intervals before the final recall, two corre-

[3] We are indebted to the administrators and teachers of the high schools in Media, Springfield, and Swarthmore, Pa., for excellent coöperation in arranging experiments

sponding groups were used. One group learned list 1, the other list 2 (Fig. 1). In this way syllables as isolated items could be compared with syllables as crowded items for a particular length of period of retention, and the same comparisons were possible with geometric figures. The inherent difficulty of a particular type of material thus was approximately a constant for a given comparison.

The nonsense syllables chosen all fall at very nearly the same level of difficulty (75 percent) according to Krueger's (9) ratings. The geometrical figures used likewise were of a nearly uniform level of difficulty, having been reproduced by about 75 percent of 120 *S*s in a previous similar experiment done under the direction of E.B.N. These assurances as to the equality in difficulty of our items permit us to assume that differences in the learning of isolated and repeated materials depend upon their isolated or crowded character, and not upon inherent differences in the difficulty of items.

FIG. 1. Stimulus series for experiments I (list 1, list 2) and II (list 3).

All scoring was done by C.E.B. The criterion for correctness of syllables at any recall was: all letters present in correct order. The correctness of geometrical figures was more difficult to judge. It was arbitrarily decided to term a figure correctly reproduced if (1) the general outline, and (2) most of the outstanding details, were present. These criteria permitted some latitude as to distortion of shapes, variation in small details if their general character was indicated, etc. For example, the number of steps drawn for a step-like figure did not matter if the 'step character' was indicated; if small circles were drawn as dots, this was accepted as correct. Permitting such departures from strictly faithful reproduction raised the absolute scores for figure recall. The procedure can be defended on the ground that after a rather large amount of experience it seemed possible to be quite consistent in the scoring. Earlier scorings

with their students. Dr. Maurice Mandelbaum and Dr. Richard Brandt of the philosophy department of Swarthmore College also kindly arranged for experiments with their classes.

TABLE I

NUMBERS OF *Ss* FOR EACH TIME INTERVAL AND TYPE OF MATERIAL (EXPERIMENT I)

Time Between Original and Final Recalls	List Learned *	Number of *Ss*
	High School	
2 min.	1	16
	2	16
30 min.	1	42
	2	42
1 day	1	23
	2	25
2 days	1	24
	2	18
3 days	1	26
	2	24
1 week	1	19
	2	16
	College	
5 min.	1	15
	2	8
1 hr.	1	10
	2	14
2 days	1	20
	2	15
5 days	1	19
	2	12
		Total, 404

* Number of list refers to Fig. 1.

then were re-checked so that approximately the same amount of leniency was used throughout.

A word should be said about a particular computation which is employed throughout a greater part of the paper. Our *Ss* were classroom groups, used because of their availability, so they were not matched as to learning ability, and their initial recall scores varied rather widely. Therefore, in studying retention, it was desirable to use some measure of *relative* amounts of change in recall scores after various time intervals. The simple ratio of final to initial score turned out to be meaningless in any case where an *S* recalled nothing at the first test and any correct items at all on the final test (this occurred a few times among isolated items, since there were but two of these in each list). Therefore, in order to utilize indications as to 'absolute' level of learning ability for any *S* we computed a learning-recall ratio, or index, according to the formula $\frac{L-R}{L+R}$, where L is the initial and R the final recall score ('learning' and 'recall' scores, respectively). These ratios for all *Ss* then were treated as scores, upon the basis of which means and S.D.s could be computed for each group in the conventional manner. It will be seen that the mean ratio of a final to initial

test can range between − 1.00 (nothing recalled at initial test, anything at final), through zero (no change), to + 1.00 (complete forgetting). Since the ratio of zero indicates no change, if the difference between a particular mean ratio and zero is greater than three times the S.E. of this mean, we have an indication that this amount of change from initial to final test is statistically reliable.

Initial Recall

Before it is possible to consider the forgetting curves for our data, it is necessary to show that we in fact are dealing with isolated and crowded material in von Restorff's sense. In Table II are presented the percentages of items correctly

TABLE II

Initial and Final Percentages of Recall for Each Experimental Group *

Groups	Interval	Cr. Syll.		Iso. Syll.		Cr. Fig.		Iso. Fig.	
		Init.	Fin.	Init.	Fin.	Init.	Fin.	Init.	Fin.
High school	2 min.	76	70	88	84	80	83	91	91
	30 min.	69	66	87	83	78	86	88	94
	1 day	72	69	100	96	*84*	94	*80*	85
	2 days	89	56	90	83	81	79	94	92
	3 days	84	71	90	78	80	76	90	92
	1 week	78	56	94	90	*90*	69	*90*	82
College	5 min.	77	71	87	75	85	81	90	90
	1 hr.	88	70	97	82	83	91	95	90
	2 days	76	44	93	87	86	78	90	88
	5 days	81	26	87	54	86	62	89	76

* Italics indicate reversals of general trend (see text).

recalled by each group of *Ss*. For the present purpose, only the percentages for the initial tests are of interest. Comparison of the recall scores of one group of *Ss*, for isolated material, with the score of an entirely different group of *Ss*, for similar but crowded material, shows a superiority of isolated material in all except two cases. These results are summarized in Table III. The absolute level of recall is in all cases rather high, but this was obtained intentionally, since our interest was in the curve of forgetting and we wished to start with a high level. In spite of this, the differences between isolated and crowded material are highly reliable. The lower part of Table III shows that such differences, comparing figures with figures, are slightly smaller than those

comparing syllables with syllables, but even these would be quite reliable were it possible to allow for the varying ability of individual groups.[4] These results make it clear that we are dealing with a genuine factor of isolation, as opposed to crowding.

TABLE III

COMPARISONS OF CROWDED AND ISOLATED MATERIALS IN INITIAL RECALL SCORES (GIVEN AS PERCENTAGES)

	Crowded	Isolated	Diff.	Student's *t* or C.R.
High school	80.1	90.2	10.1	7.57
College	82.8	91.0	8.2	4.48
Syllables	79.0	91.3	12.3	4.98
Figures	83.3	89.7	6.4	2.67

FORGETTING

The results of the final recall tests, given from two min. to one week after the initial recall test, are presented in Tables II and IV. The former table gives a clear impression of the absolute level of recall after the various intervals of time, but accurate comparisons between groups are impossible without relating each final score to the initial score by the same group. Of even greater importance, however, is some estimate of the reliability of any loss (or gain). This can be obtained from the indices of forgetting presented in Table IV, and they will be used throughout the subsequent discussion. The data of this table are presented graphically in Figs. 2*a* and 2*b*.

Isolated Material.—Our first clear result is that a comparison of the size of the mean indices with their corresponding

[4] In computing Student's *t*, for the comparisons of crowded and isolated items shown in the upper part of Table III, use was made of the existing pairings of data thereby 'controlling' that part of variation in scores which was due to variation in ability of the various groups. That is, indices of retention for syllables as crowded material were compared with indices for figures as isolated material, for all groups having this combination. With these comparisons were combined all those for groups having figures as crowded material and syllables as isolated. The constant error (see discussion of scoring) which raised the indices for figures thus operated to favor isolated material in half of the pairings and to favor crowded material in the remaining pairings from which *t* was computed.

With no possible way to take account of variations in ability of groups in obtaining the C.R.s shown in the lower part of Table III, we have used the standard formula for the S.E. of a percentage. Because of the assumptions which must be justified before this technique is used, we do not feel that it is fully applicable here. It therefore represents a 'last resort.'

TABLE IV

MEAN RATIOS OF FINAL TO INITIAL RECALL SCORES, WITH THEIR S.E.s *

Groups	Interval	Cr. Syll.	Iso. Syll.	Cr. Fig.	Iso. Fig.
High school	2 min.	.046±.028	−.021±.069	−.021±.011	.000±.029
	30 min.	.059±.030	.048±.053	−.059±.019	−.040±.020
	1 day	.081±.038	.027±.018	−.059±.015	.013±.032
	2 days	.275±.076	.056±.066	.012±.012	.014±.037
	3 days	.095±.023	.097±.090	.056±.013	.000±.018
	1 week	.167±.051	−.021±.018	.160±.015	.052±.046
College	5 min.	.043±.019	.017±.130	.025±.027	.000±.000
	1 hr.	.128±.016	.095±.070	−.061±.021	.033±.033
	2 days	.284±.065	.067±.072	.008±.046	.000±.061
	5 days	.607±.064	.221±.069	.161±.049	.087±.050

* The ratios were computed from each individual's scores, according to the formula: $\frac{\text{Learning} - \text{recall}}{\text{Learning} + \text{recall}}$ (see text). The mean ratio and the S.E. of the mean for each group were then computed from the individual ratios. A negative ratio indicates reminiscence, a positive, forgetting.

S.E.s (Table IV) shows that there are almost no significant changes for the isolated material. Of the 20 indices for isolated material, but one is statistically significant, a second one possibly so. In contrast, for the crowded material, 11 of 20 indices are more than three times the size of their S.E.s; three of the remaining nine are more than twice their S.E.s. The lack of significant change in isolated material cannot be attributed to a lack of reliability, for even were the S.E.s as

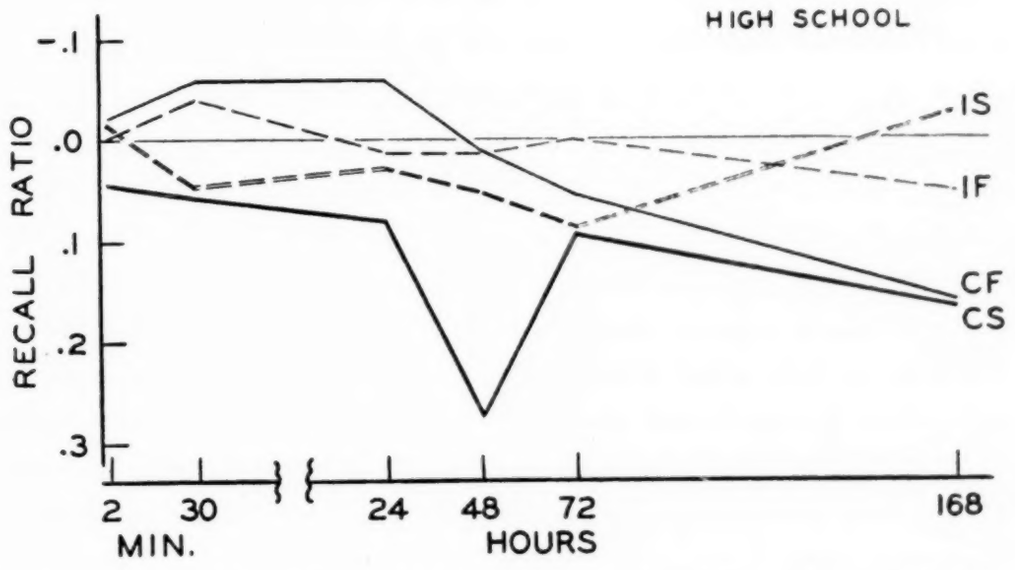

FIG. 2a. Curves of forgetting for high school groups, based on the indices of Table IV.

low as those for crowded material, there still would be but one significant change, in isolated syllables, after the longest interval, with college students.[5] There perhaps is an inherent difference between the two kinds of material. The geometric figures are slightly more stable, showing a mean change for all the intervals of .016 (roughly equal to a loss of three percent), compared with a mean change of .059 (loss of 11 percent) for the syllables.

It should be noted in passing that the fact that these values do not indicate a *gain* in recall scores for the isolated material is significant in itself. Recent studies have sug-

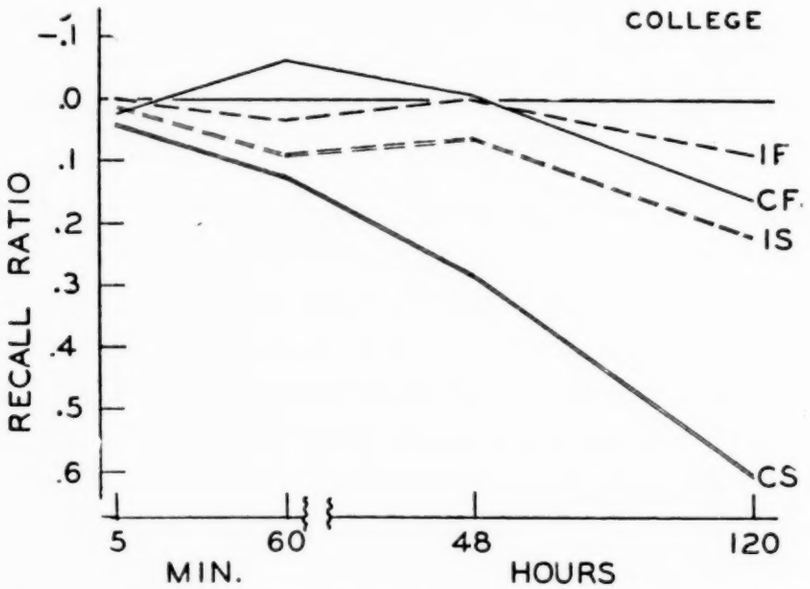

FIG. 2*b*. Curves of forgetting for college groups, based on the indices of Table IV.

gested that the recitation incidental to an initial test of recall may raise the level of any subsequent test (**2**, **3**). It would be difficult to prove that such an effect was not present in our results, simply being obscured by forgetting which is more obvious. But such a presumption is at least very unlikely in those cases where there is not significantly less forgetting after two to five min. than there was after a week. All of our results for the isolated material suggest very little forgetting (or very little *gain*) for the first two days or more, and *pari passu*, little likelihood that the final recall test is being favored systematically.

[5] The smaller number of isolated items produces greater unreliability than is the case with crowded items. This cannot be avoided, by the nature of the experiment.

Crowded Syllables.—The second clear-cut finding is that during the time when the isolated material showed little change, the crowded material was being forgotten to a significant extent. To look first at the final level (Table IV, Figs. 2*a* and 2*b*) reached after five days and a week, respectively, by the crowded material, it will be seen that indices for both materials and for both groups of *Ss* show significant forgetting, and that the crowded material has been forgotten more than the corresponding isolated material in all four cases. These differences are not all equally significant but taken together indicate a high reliability. The C.R.s for the geometrical figures are 1.06 and 2.25 for the college and high school groups respectively; for the syllables, they are 4.11 and 3.79 (all showing superior retention of isolated material). Disregarding the *kind* of material used, in order to make comparisons *S* by *S*, we find that for high school students the mean difference is .0145 (Student's $t = 2.97$); for the college students the difference is .0317 ($t = 4.15$). Both differences are highly reliable.

In the case of one kind of material, the syllables, the more rapid forgetting of the crowded items is apparent from the earliest time interval tested. Inspection of Table IV and Figs. 2*a* and 2*b* will show that the crowded syllables are consistently below all the other kinds of material. In the more uniform results of the college groups the difference between crowded and isolated items becomes progressively larger from one interval to the next. Adequately matched high school groups doubtless would show the same result. This result holds true for the syllables even though their initial level of recall was the lowest: the crowded syllables were remembered least well on the initial test and then were forgotten *proportionately* more rapidly.

Crowded Figures.—The third clear fact in our results is the evidence for reminiscence. Seven of the 40 indices in Table IV have negative signs, indicating a rise from initial to final test. Three of these are nearly or more than three times as large as their S.E.s, indicating a significant gain. All three occur with the crowded figures at intervals between 30 min.

and one day. A glance at Figs. 2*a* and 2*b* shows quite clearly the extent of the effect.

It is important that certain things about this evidence of reminiscence be specified in greater detail. First, we should apply two further criteria to test the genuineness of the rise in our curves. G. O. McGeoch (**10**) has proposed that the number of individual *S*s showing a gain be compared with the number showing a loss, as a measure preferable to simply mean gain or loss. When this criterion is applied to our data, the results shown in Table V are obtained for crowded figures,

TABLE V

PERCENTAGES OF *S*s SHOWING GAIN IN FINAL OVER INITIAL TEST, FOR CROWDED FIGURES (REMINISCENCE), COMPARED WITH NUMBER SHOWING LOSS

Interval	*N*	Percentage Showing Gain	Percentage Showing Loss	Difference ($G - L$)
		High School		
2 min.	16	19	0	19
30 min.	42	45	14	31
1 day	25	48	0	48
2 days	18	17	28	−11
3 days	24	17	42	−25
1 week	16	0	69	−69
		College		
5 min.	8	12	37	−25*
1 hr.	14	36	0	36
2 days	15	13	46	−33
5 days	12	25	58	−33

* Probably an atypical value; it is based on a small number of *S*s.

the only material showing reliable evidence of reminiscence by the criterion of mean gain. These percentages show an almost point-by-point correspondence with the mean indices. At the one hr. and one day intervals the number of *S*s showing gains is quite impressive, especially in view of the fact that no *S*s show losses. The fact of reminiscence is demonstrated; its magnitude is not clearly shown by such a gross comparison.

A second test for reminiscence would require that a comparison of identical tests given at two intervals after the initial learning to different groups should show a reliable rise

in the level of performance. The reason for this requirement was indicated in the discussion above. Three differences may be examined in this way, the 30 min. level vs. two min. level and the one day vs. two min. for the high school groups, and the one hr. level vs. five min. level for the college groups. These differences, from Table IV, are .048, .048 and .086, respectively. Compared with their respective S.E.s, they give C.R.s (for reliability of the gains) of 2.18, 2.59 and 2.51. There can be little doubt that there is significantly more reminiscence after from one hr. to one day than there is after two to five min., for the crowded figures in our lists.

The fact that reminiscence occurs in the case of crowded figures is clearly in line with our expectations. Also, the fact that it does not occur reliably in the isolated material accords with prediction. There remains the question of why it does not occur with crowded syllables. Ward (**15**) and Hovland (**4**) have shown that the effect *can* be found under certain limited conditions. Either the difference in method (Ward's and Hovland's anticipation method contrasted with our free recall) or the difference in time intervals used, or both, might be responsible for our failure. Their results suggest a small reminiscence effect with syllables which disappears very quickly. If there was any such effect present in our experiments, it probably was offset by the marked forgetting present with this material by the time of our first tests.

It is pertinent to remark that this difference in behavior of figures and syllables is not at all unique. Almost all of the investigators mentioned above who have had occasion to use these materials have found consistent differences. Unpublished experiments conducted by E. B. N. for other purposes have consistently demonstrated the presence of reminiscence in the case of figures and its absence in the case of syllables. An adequate account of the systematic differences between kinds of material is largely speculative at the present time.

Crowded vs. Isolated Material.—For purposes of discussion it is convenient to separate reminiscence and forgetting. Reminiscence seems to be an effect which occurs when certain special conditions are fulfilled. What all of those conditions

are cannot be specified adequately in terms of the present findings. It has been suggested, and this experiment is consistent with the explanation, that reminiscence occurs when there is a relatively large amount of intra-serial interference.

Considering forgetting apart, this experiment has shown that the forgetting of crowded material is relatively more rapid than the forgetting of isolated material, a finding that is contrary to the prediction made at the outset. Forgetting of isolated material does not take place to a significant extent during the one week interval which we tested. It is probable that still longer intervals would reveal such forgetting. Forgetting of crowded material starts at the shortest intervals tested (syllables) and is so great at the longest periods that it overcomes fairly marked reminiscence (figures).

Discussion

It could be argued that the outcome of our experiment necessitates substantial revision of some of the assumptions set forth in the introduction to this paper. Forgetting, it might be said, is independent of external (*e.g.*, retroaction-producing) factors, and the rapid loss of crowded material is simply a function of a weaker original impression: we only have an additional example of the principle, the weaker the 'bond,' the more quickly it will fade out and become ineffective. But before reverting to this or any other equally superficial view of memory, we should like to examine more closely the formulation of our problem.

As a starting point, reference should be made to certain results recently published by one of the writers (**12**). In this case it was shown that single lists of syllables were forgotten more rapidly, after the first short interval of time, than were three lists, each equal in length to the single list, learned in quick succession. It was argued that the single list was relatively isolated, in contrast to the three lists learned at one sitting which 'crowded' each other. Certainly some factor such as massing or crowding, able to account for the difference, was at work. Thus it was argued that the 'isolated' list was forgotten more rapidly and the 'crowded' lists were

retained better. This experiment, then, and our present one seem to produce contradictory results. In what respect do they differ?

In her first paper von Restorff (**14**) brings out an important point which has not been mentioned here. She showed that an item is not isolated simply because it differs from each other item in the series, but rather that its isolation is equally dependent upon the homogeneity or similarity of the remainder of the list. Isolation as it was present in her main series of experiments, and probably also in ours, is a standing out of a single dissimilar item on a ground of many similar items. This structural characteristic of the list is a necessary condition for the existence of an isolated item in von Restorff's sense.

It is apparent now that the meaning given to the term isolation in the discussion at the outset of this paper is a different one from that just outlined. In the meaning first implied, isolation would signify having no near neighbors, standing without any strongly or sharply defined relationship to the surroundings, as in the experiment with the single vs. triple lists (**12**). This might be called 'absolute isolation.' In von Restorff's sense and in our *experiments*, isolation implies that an item has the character of a figure upon a ground; an item has many immediate neighbors and is related very strikingly to those neighbors, related by contrast. We suggest that the difference between these two conceptions of isolation will explain the contradiction between our assumptions and the outcome of our experiment, and also the difference between this experiment which employed 'figural isolation,' and the earlier experiment (single vs. triple lists) which employed 'absolute isolation.'

It is possible tentatively to set up a two-fold principle to explain differences in rates of forgetting in these differing situations. Such a principle would state that those items will be most rapidly forgotten which are readily available to chance disturbing or interfering forces, and which at the same time are only weakly related to surrounding items. This is the case which we have called 'absolute isolation.' On the other

hand, those items will be forgotten least rapidly which are available due to their isolation, *but* which at the same time are strongly imbedded in the series. This is the case of isolation described by von Restorff and used in our experiment. The single item stands out by virtue of the structure of the series. It is a figure on a ground. It is isolated only because of the homogeneous ground, a matrix which both establishes the isolated item and at the same time protects it. Finally, the crowded items of a series of this latter type of structure will be forgotten more rapidly than the isolated items of the same series because they are not nearly as accessible as the isolated items and will be hard to recall. At the same time, this very inaccessibility may protect them somewhat from retroactive interference. They also are imbedded in the list and will be less subject to forgetting than are items which bear no close relation to their surroundings, *i.e.*, in the case of 'absolute isolation.'

Such a principle would mean little were it not possible to test it. An experiment by von Restorff (**14**) suggests one way of testing our present hypothesis. Her experiment consisted of using a stimulus series in which the character of 'figural isolation' had been destroyed by making all the items in the series as different from one another as possible. She found that fewer items of a heterogeneous series constructed in this way were recalled than isolated items in an otherwise homogeneous list, but more were recalled than was the case for crowded items in the homogeneous list. Measured in terms of availability, the heterogeneous list stood midway between the isolated and crowded items of the homogeneous list. If our reasoning has been correct, the *forgetting* of such a heterogeneous list should be at least as rapid as for the crowded items in the lists we actually used because the crowded items are less accessible. If a sufficient degree of heterogeneity could be achieved, the forgetting should be even more rapid even though the initial recall is better. We were able to test this expectation in a preliminary way.

Experiment II

Experiment II was conducted in all respects just as was Experiment I, with the single exception of the material presented. The stimulus list (list 3) is shown in Fig. 1. It will be seen to consist of three items which might be classified as verbal, an adjective, a nonsense syllable, and a consonant; three items which were geometrical figures, an outline of an object, a fish, and the radical sign; and two items which were numbers, one with three digits, the other with only one. The list is more heterogeneous than those used previously and the items are about as varied as our general type of stimulus material and method of presentation will allow. College groups only were used; they were re-tested after one hr., two days, and one week, as with the previous procedure.

The results of this experiment are summarized in Tables VI and VII. These tables may be compared roughly with Tables II and IV. We have divided the new stimulus list into the three categories mentioned above, for the purpose of scoring. The first two of these groups, the verbal and the geometrical items, may be compared with the syllables and figures respectively of Experiment I, but this comparison is only approximate at best, and all of the subsequent discussion must be read with this limitation in mind.

The mean level of initial recall (three categories of items combined) was high in all three groups of *Ss*. The mean of the groups combined, 90.7 percent, compares favorably with the mean for isolated items in the first experiment, 91 percent, but little significance can be attached to such a comparison because of the lack of any objective control of the difficulty of the material. Only relative measures, such as the ratios presented in Table VII, can be considered seriously.

The rate of forgetting of this heterogeneous material was one of the most rapid found in any of our work. After one week recall had dropped from 89 percent to 51 percent (all categories of items within the list combined), an amount of forgetting exceeded only by the college group having crowded syllables in the first experiment. The more detailed comparisons in Table VII bring out the same point. At the end

TABLE VI

RECALL SCORES IN THE VARIOUS CATEGORIES OF STIMULI (PERCENTAGES) FOR INITIAL AND FINAL TESTS ON A HETEROGENEOUS LIST (COLLEGE *Ss*)

Interval	*N*	Verbal		Geometrical Figures		Numbers	
		Init.	Final	Init.	Final	Init.	Final
1 hr.	8	96	96	92	92	94	94
2 days	12	94	64	88	70	92	71
1 week	35	90	50	85	57	93	43

TABLE VII

MEAN INDICES OF RETENTION FOR A HETEROGENEOUS LIST COMPARED WITH VALUES IN EXPERIMENT I (COLLEGE *Ss* IN BOTH CASES)

Interval	Material	Heterogeneous	Isolated	Crowded
1 hr.	Verbal	.000±.000	.095±.070	.128±.016
	Figures	.000±.008	.033±.033	−.061±.021
	Numbers	.000±.057		
2 days	Verbal	.247±.078	.067±.072	.284±.065
	Figures	.149±.041	.000±.061	.008±.046
	Numbers	.137±.061		
5 days	Verbal		.221±.069	.607±.064
	Figures		.087±.050	.161±.049
1 week	Verbal	.375±.064		
	Figures	.215±.033		
	Numbers	.457±.062		

of one hr. no change of any significance had taken place. At the end of two days the verbal material (Experiment II) had dropped more than the isolated syllables (Experiment I) but not as much as the crowded syllables. The geometrical figures in the heterogeneous list had dropped significantly more than *either* isolated or crowded figures of the first experiment. Comparisons at the end of one week can be made only with the corresponding five day group of the first experiment, but the order of the differences is exactly the same: the verbal material (second experiment) is below the isolated syllables (first experiment) and the figures (second) are below either the isolated or crowded figures (first). The exception to our expectation occurs both times in comparisons with the crowded syllables. This may be explained partially by recalling that

the verbal material of the second experiment contains a meaningful word and consonant in addition to the nonsense syllable, so that forgetting for this category should not proceed so rapidly. The mean ratio for the syllable alone shows more forgetting (.457) than for the three verbal items combined (.375), but this difference is not very significant because the sample is so small.

The most important fact about these results is that they establish conclusively the difference between an item having figural isolation in the sense of Experiment I, and an item in a heterogeneous list which differs just as much from its neighbors but lacks any figural character, as in Experiment II. In general, such a term as isolation may not be applied without regard for the structure of the series in question; the same must be said of terms such as similarity, identity, and others.

Furthermore, these results lend support to the view advanced at the outset of this paper, that memorial material unrelated to its surroundings and isolated *in an other than figural* sense will be forgotten more rapidly than more homogeneous material. Our results actually demonstrate this point when geometrical figures are used as material. The results for verbal material fail to support this conclusion but there is reason to believe that better experimental procedures would produce a different outcome. The very marked increase in the rate of forgetting in Experiment II over the isolated material of Experiment I make it probable that a more carefully selected heterogeneous list would be forgotten even more rapidly.

In conclusion, we believe that our experiments and the interpretation which we have given them support the interference theory of forgetting. At the present time there certainly is no other view which is adequate for such differential rates of forgetting as are reported above.

Summary

In our main experiment we compared the rates of forgetting of isolated and crowded materials over various intervals up to one week. In a list of eight stimulus items, two of one

kind of material were called 'isolated'; six of a different kind of material were termed 'crowded.' Contrary to expectations, crowded items were forgotten relatively more rapidly than isolated. But reminiscence did occur, and in accordance with our expectation, only with crowded items. An explanation of the results, involving the difference between isolation in the sense of having no near neighbors, and isolation as a figural character in an otherwise homogeneous series, was developed. A second experiment demonstrated the validity of this distinction.

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ROTE AND LOGICAL RECOGNITION MEMORY

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Does the distinction frequently made between rote and logical memory refer to differences in the kind of material, to the method of memorization, to some combination of the material and the method of memorization, or does it also imply a difference in ability? In a review of logical learning and retention (**4**) Welborn and English conclude that "different factors operate in substance memory and in rote memory," and that "substance memory may have distinct laws from those governing nonsense syllables," whereas Reed (**3**) states "Memory for prose substance is thought by some psychologists to be totally different from memory for rote learning, but it probably differs from it in degree rather than in kind." If the distinction is one of kind of material and method of memorization only, individuals would be expected to maintain their relative rank, irrespective of the rote or logical nature of the memory tests administered to them. On the other hand, if the distinction also involves a difference in memory ability, some individuals would be expected to vary in their relative rank, depending upon whether the test consists of rote or logical material. This experiment will attempt to find whether individuals tend to maintain their relative rank on both rote and logical recognition memory tests involving certain restricted materials or whether they tend to vary in their relative rank in accordance with the rote or logical character of the material to be memorized. If we find that the former is the case, then the distinction between rote and logical recognition memory does not involve different abilities, while if the latter is the case, the distinction between

rote and logical recognition memory also involves a distinction in ability.

The nature of the present problem and the procedure involved is like that of a preceding paper on Visual and Vocal Recognition Memory (2), the two studies differing only in respect to the materials used. In the first paper we demonstrated that there are individual differences in ability to use visual and vocal cues, and therefore that recognition memory involves visual and vocal components. In the present paper, we shall give evidence showing that it also involves rote and logical components.

Previous experimenters on this problem of rote and logical memory have generally relied upon the score on a single list of rote materials as a measure of ability to memorize rote material and the score on another list of logical material as a measure of ability to memorize logical material. It would be scientifically more satisfying to use the scores for a number of lists of rote and logical materials, and to use the average score of at least two presentations of each list. This has been done in this experiment by using series of lists, each series being made up of five parallel forms, and each list being administered twice, the two presentations being separated by two to three months.

Part of the material to be memorized should be such that its meaning or significance gives little or no aid to the subjects when they are tested for their memory of this material, while other material should be such that its meaning is of distinct aid to the subjects when they are tested later. Data upon material of this nature were gathered in connection with a previous study of memory (1) and inasmuch as it is particularly appropriate for the purpose of the present study, it has been used again. Since the experimental conditions, etc., under which these data were gathered have already been reported in detail, they will not be repeated here except to indicate those aspects which are essential to an understanding of the results reported in the present study.

While many kinds of material might be used, words were used in this experiment since their presentation can be more

readily controlled. A word can be recognized on the basis of its visual appearance, the auditory or kinaesthetic cues involved in its pronunciation (hereafter termed vocality), or on the basis of its meaning. If a subject relies upon either the visual appearance or vocality of a word in recognizing it, he is using rote memory, whereas if he relies upon the meaning of a word, he is using logical memory. By using words, and testing for memory by means of the recognition method with specific distractors, it may be possible to differentiate between subjects using rote and logical recognition memory. Recognition lists were therefore made in which the distractors were systematically varied in visual appearance, vocality, the combination of visual appearance and vocality, and in meaning. Accordingly, groups of words were selected of such character that other words could be found that have specific relationships to the first word. One group of words was chosen because for each, another word, alike in meaning and differing only in visual appearance could be found; a second group of words was collected because for each word another word could be found which differed only in vocality; a third group of words was selected because for each word a synonym could be found; and a fourth group of words was selected because for each word another word alike in visual appearance and vocality but differing in meaning could be found. These groups are E, F, C, and G, of the previously reported study (1), and the same letters will be used to designate them here. Examples of these words are included in Table I.

In Group G, both words of a pair should have the same visual appearance and vocality but should differ in meaning. Since it is impossible to designate the specific meanings of these words without the use of a context, it was necessary to make such designations by arbitrarily inserting or using a context. This was done by placing the context in parentheses, as 'bark (of dog)' for one and 'bark (of tree)' for the other. Since it is quite possible that the subjects might tend to react to the words in the parentheses, as '(of dog)' and '(of tree)' and disregard the word 'bark' entirely, the words in parentheses were made less conspicuous by using smaller type.

TABLE I

RELATION BETWEEN THE WORDS OF A PAIR IN THE EXPOSURE AND RECOGNITION LISTS

Group	Number Words in Each Recognition List	Words Alike in Respect to:	Words Different in Respect to:	Example
E	44	Vocality Meaning	Visual appearance	through thru
F	26	Visual appearance Meaning	Vocality	con'tem-plate con-tem'plate
C	48	Meaning	Visual appearance Vocality	rely depend
G	66	Visual appearance Vocality	Meaning	bark (of dog) bark (of tree)

The exposure lists included one word of each of the pairs. The corresponding recognition lists contained both words of the pairs, the additional one serving as a distractor to that presented in the exposure list. Since the relation between the associated words in a recognition list was constant, the use of a particular mode or combination of modes was favored for each list.

Inspection of Table I shows that while meaning, vision, and vocality could have been used in memorizing the words in the exposure lists, the subjects could not use meaning to distinguish between the words of a pair in the recognition lists in series E, F, and C, but could use meaning in series G. If a subject is relatively superior in the use of visual or vocal cues (*i.e.*, in series E, F, or C), as compared with meaning (*i.e.*, series G) he is relying upon rote memory, whereas if the opposite is the case, he is relying upon logical memory. Accordingly, if we can find such subjects, we thereby demonstrate that there are individual differences in ability to utilize rote and logical memory in recognizing words and therefore that the ability to memorize words involves a rote and a logical component.

The words were serially exposed on a screen by means of a film and a projection machine in order to make it possible to give the experiment to a group of subjects at one time and to control the exposure time for each word.

The subjects were told that a series of words would be shown on the screen and they were instructed to memorize the words so as to be able to recognize them when presented as part of a longer list. No instructions were given as to the mode of memorizing. The exposure list was presented but once. Each word was exposed for two seconds.

The recognition list was shown immediately after the exposure list, the subjects being instructed that all the words in the first (exposure) list were in the second (recognition) list, interspersed with other words. Nothing was said about the character or number of the distractor words. The subjects were asked to check in the proper blank space on a prepared data sheet which words were in the exposure list and which were not. They were told to guess whenever in doubt. A response was thus made to every word in the recognition list. This list was also exposed but once. To permit the subjects time to respond, the exposure time for each word was three seconds, one second longer than in the exposure list.

A total of 202 high school and college subjects participated in and completed the experiment.

The majority of the subjects were not familiar with psychological experiments, and so five preliminary practice lists with nonrelated distracting words were given in order to offset as much as possible the variability in the scores that might result from this lack of familiarity with the testing procedure. No use was made of these data.

Because the mean and standard deviation of the average scores of the tests differed, no direct comparison could be made between an individual's average scores on the tests in one series and those in another. Some form of comparable scores had to be used. Accordingly, the individual's average scores on each of the tests were transmuted into normalized standard scores, obtained by transmuting the raw scores into percentile ranks, and these in turn into standard scores by means of Kelley's tables.

The standard scores thus obtained, however, do not permit an immediate comparison between an individual's score on the five tests in one series as compared with those in

another without the adoption of some arbitrary quantitative criterion. It was decided to select for further study only those subjects whose scores were higher on at least four of the five parallel tests in one series than on four or five in another series. The advantage of this method over other arbitrary methods is that it selects only those individuals whose response to one kind of material differs in a fairly consistent manner in reference to another. In order to illustrate this basis of selecting subjects, an example is given in Table II

TABLE II

EXAMPLE SHOWING CONSISTENTLY HIGHER SCORES IN SERIES G THAN IN SERIES C

Subject Number	Series	Test Number				
		1	2	3	4	5
74	G	0.49	0.17	0.32	0.29	1.21
	C	−0.12	−0.14	−0.43	−0.46	−0.87

for subject number 74. This table shows that the scores on each of the five parallel forms are higher in series G than any in series C.

The number of subjects who made consistently higher scores on the tests in series G as compared with those in series E, F, and C, is included in Table III. The size of the differences between the scores on the parallel forms in each series for each group of subjects selected is indicated by the mean scores included in this table.

Let us consider the subjects in Group 1. The scores for these subjects are consistently higher on the tests in series E than on those in series G. In series E the words of a pair differ only in spelling, so that there is little or no possibility for a subject to differentiate between them by the use of vocal cues or on the basis of meaning. In series G, on the other hand, while the words of a pair have identical spelling, each has a specific context immediately beneath it, so that a subject would be aided in his attempt to distinguish between them if he made use of the contextual meaning associated with each word. Since these subjects were consistently superior in series E as compared with series G, it would appear that

TABLE III

MEAN SCORES OF SUBJECTS CONSISTENTLY SUPERIOR (OR INFERIOR) IN SERIES G AS COMPARED WITH SERIES E, F, AND C

Group	No. of Subjects	Comparison		Mean Standard Score on Each Test				
				1	2	3	4	5
1	29	E higher than G	E	.22	.26	.48	−.01	.35
			G	−.59	−.49	−.54	−.58	−.46
3	36	G higher than E	G	.16	.25	.26	.23	.15
			E	−.67	−.40	−.58	−.60	−.55
4	52	F higher than G	F	.35	.20	.37	.39	.38
			G	−.50	−.52	−.44	−.52	−.40
6	44	G higher than F	G	.63	.59	.53	.66	.58
			F	−.35	−.24	−.37	−.51	−.44
7	45	C higher than G	C	.42	.30	.39	.43	.33
			G	−.47	−.42	−.34	−.35	−.29
9	37	G higher than C	G	.27	.55	.34	.44	.35
			C	−.51	−.30	−.43	−.64	−.44

relative to the entire group, these subjects were better able to make use of visual cues alone than they were able to make use of the specific meaning of the words to be differentiated. We might say, then, that these subjects relied primarily upon vision rather than upon meaning in their attempt to memorize the words, or that they made use of a rote method of memorizing rather than a meaningful or logical method. The subjects in Group 3, on the other hand, were better able to make use of the specific meaning of the words than they were able to make use of visual cues alone. That is, they tended to use logical memory rather than rote memory.

The fifty-two subjects in Group 4 are consistently superior in series F as compared with series G. In series F the paired words differ only in syllabication and in position of the accent mark, so that a subject would be aided in his attempt to distinguish between them if he used vocal cues; while in series G, where each stimulus word has a specific meaning appended, a subject would be aided in his attempt to distinguish between the related stimuli if he made use of the meaning given. These subjects in Group 4 apparently are more adept in using

vocal cues than in using meaning or, in other words, they tend to use rote memory rather than logical memory. The subjects in Group 6, on the other hand, having relatively higher scores in series G as compared with series F, presumably use logical memory to greater advantage than they use rote memory.

The subjects in Group 7 have consistently higher scores in series C as compared with series G. In series C the words of a pair are synonyms, so that a subject could make use of both vision and vocality to aid him in differentiating them, whereas a subject could use meaning in differentiating between the related stimuli in series G. These subjects in Group 7, therefore, appear to make use of a combination of visual and vocal cues, rather than meaning, or, in other words, they use rote memory rather than logical memory. On the other hand, the thirty-seven subjects in Group 9, having consistently higher scores in series G than in series C, rely upon meaning primarily, rather than upon a combination of visual and vocal cues, or use logical memory rather than rote memory.

There are, however, other possible explanations for the results. If we knew all the subjects in the experiment were able to use the visual cues in each series with equal facility, we could be more certain that the differences found have been correctly interpreted. But it is quite possible that the subjects differ in their ability to use the different visual cues involved in each series; *i.e.*, in series E and C the words could be differentiated on the basis of spelling, in series F on the basis of the syllabication and the position of the accent mark, and in series G by the visual differences in the character of the inserted context. If the subjects differ in their ability to use the different visual cues, this might account for the differences found in these groups of subjects. An alternative explanation for the results obtained, then, is that the subjects in each group excelled in an ability to use a specific visual form or pattern as contrasted with another specific visual form or pattern ability. If this is the case, it would be necessary to postulate that there are a number of fundamentally

different visual characteristics involved in the recognition of words having those aspects included in this experiment, each characteristic demanding a specific visual ability. Whether such specific visual abilities exist, their number, and their nature, cannot, of course, be answered by this experiment.

There is yet another possible explanation for the results when series C is involved. In this series, while the related words are synonymous, there is nevertheless some shade of difference in their meaning, and it is possible that some words in the exposure lists in this series have other more familiar associations for these subjects than the related synonymous distractor. If this is the case, meaning might have been used to advantage, introducing another logical component. Inasmuch as there is a considerable group of subjects who are consistently superior in series C as compared with series G, and another group consistently superior in series G as compared with series C, the same meaning component could not have been involved in both C and G. A few subjects reported that the specific meaning given to the words in series G seemed to interfere rather than facilitate the memorization and recognition of the stimuli. If enough subjects were so influenced, this might also account for the results. Some subjects may have attempted more or less aggressively to read their own meaning into the words in the exposure lists and they would therefore be aided in memorizing and recognizing the words in series C, while they would be detrimentally influenced in series G. They would therefore be found in Group 7. Other subjects, on the other hand, may have found it convenient to use meaning when it was specified, as in series G, but did not find it convenient to use meaning when it was not specified, as in series C. These subjects would therefore be found in Group 9. This explanation would imply that some individuals tend to search actively for the meaning and significance of objects and events while other individuals tend to appreciate the meaning of an object or event only when it is pointed out to them.

It is of scientific interest to attempt to check these alternative explanations. Inasmuch as a considerable number of

subjects appear in more than one group, it is possible to do so. If our first interpretation is correct, several of the groups must logically contain the same subjects. Further study of the data was therefore made in order to determine the extent to which the groups are composed of the same subjects. This is summarized in Table IV.

TABLE IV

EXTENT TO WHICH GROUPS ARE COMPOSED OF THE SAME SUBJECTS

Group		Group		$E \overset{1}{<} G$	$E \overset{2}{=} G$	$G \overset{3}{<} E$	*n*
4	F<G	7	C<G	8	11	1	20
		8	C=G	8	18	1	27
		9	G<C	1	4	0	5
5	F=G	7	C<G	5	13	1	19
		8	C=G	5	54	11	70
		9	G<C	0	12	5	17
6	G<F	7	C<G	2	3	1	6
		8	C=G	0	18	5	23
		9	G<C	0	4	11	15
			n	29	137	36	202

Inspection of this table reveals that if an individual has consistently higher (or lower) scores in series G as compared with a second series, he is much more likely to have higher (or lower) scores in series G as compared with a third than vice versa. Further discussion, therefore, will be limited to a consideration of those individuals who have consistently higher (or lower) scores in series G as compared with two (G being equal to the third) or all three of the other series. The individuals are included in Table V.

The subjects common to groups 1, 5, and 7 apparently are superior in the use of vision, while those common to groups 2, 4, and 7 are superior in vocality. These subjects use one rote cue more effectively than another. In groups 1, 4, and 8, the presence of two rote cues is apparently distracting for these subjects use either one alone more effectively than the two rote cues together. The subjects common to groups 1, 4, and 7 apparently use vision, vocality, and the combination of these two cues with facility. The thirty-two subjects in

TABLE V

NUMBER OF SUBJECTS WHO HAVE CONSISTENTLY HIGHER (OR LOWER) SCORES IN SERIES G AS COMPARED WITH TWO OR THREE OTHER SERIES

Groups	Comparison	*n*	Interpretation Subjects Relatively Superior in the Use of
1, 5, 7	E<G F=G C<G	5	Vision
2, 4, 7	E=G F<G C<G	11	Vocality
1, 4, 8	E<G F<G C=G	8	Either vision or vocality alone
1, 4, 7	E<G F<G C<G	8	Vision and vocality alone or together
n		32	Rote memory
3, 5, 9	G<E G=F G<C	5	Meaning
2, 6, 9	G=E G<F G<C	4	Meaning
3, 6, 8	G<E G<F G=C	5	Meaning
3, 6, 9	G<E G<F G<C	11	Meaning
n		25	Logical memory

these groups consistently make use of rote cues rather than meaning. On the other hand, the twenty-five subjects common to groups 3, 6, 9, and 3, 5, 9, and 2, 6, 9, and 3, 6, 8, are consistently superior in series G as compared with two or three remaining series. While these groups differ in respect to which they are superior, they all indicate a consistent use of meaning or logical memory. Since this interpretation is consistent with that first made, we can disregard the alternative interpretations given.

To sum up briefly, series of visual recognition tests of words favoring the use of rote memory (*i.e.*, vision, vocality, and vision and vocality combined), and the use of logical memory (*i.e.*, meaning), were given to 202 subjects. A considerable number of subjects was found to be consistently superior (or inferior) in the meaning series as contrasted with one of the rote series. Some of these subjects are consistently superior (or inferior) in the meaning series as contrasted with two rote series. Others are consistently superior (or inferior) in the meaning series as compared with all three rote series. From this it follows that there are individual differences in ability to utilize rote and logical memory, and therefore that recognition memory involves at least a rote and a logical component.

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BILATERAL DIFFERENCES IN BRAIN POTENTIALS FROM THE TWO CEREBRAL HEMISPHERES IN RELATION TO LATERALITY AND STUTTERING

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The relationship of the two cerebral hemispheres in the control of such complex processes as speaking, reading, and writing and in the possible determination and maintenance of laterality of certain motor functions has long been a problem. Theories postulating a 'master' or 'dominant' hemisphere as a unifying principle of control have arisen largely on the basis of clinical evidence in connection with the interference or abolition of the speech function by cortical lesions in the so-called 'dominant' hemisphere. Other evidence of an indirect kind has come from studies which have shown an association between ambidexterity or mixed laterality and disorders of speech, reading, and writing. No direct anatomical, histological, or physiological evidence has differentiated the two cerebral hemispheres so far as the unification and integration of their activities in terms of a dominant hemisphere is concerned.

One of the earliest studies of cerebral action potentials made in this country was a study by Travis and Dorsey (**6**) comparing the electrical activities of various homologous areas in the two cerebral hemispheres of the rat. They found similar patterns of activity in bilaterally homologous areas but a higher degree of synchronism of the potential changes in the motor regions of the two sides than in the occipital or auditory areas. Travis and Knott (**7**) studied brain potentials in normal and stuttering subjects and found small but significant differences in the frequency and amplitude of the alpha waves during silence and speech, but no observations on bilateral differences in the two hemispheres were reported.

A recent brain potential study by Raney (**5**) comparing the bilateral electroencephalograms of identical twins in relation to laterality functions showed a greater percentage and amplitude of alpha wave activity on the non-dominant side of the head. He interpreted this as indicating that the non-dominant side is less activated or less excitable than the dominant side. He suggested that lateral dominance may be related to the cortical excitatory state of the two cerebral hemispheres.

In a previous report (**4**) I called attention to the tendency for bilaterally recorded occipital alpha waves to be in phase or synchronized. This was true even in very young infants. There were, however, in most records some indications of asynchronization of the activity of the two hemispheres. These observations led to the present study of bilateral differences in the simultaneously recorded electrical activity of the two cerebral hemispheres in relation to laterality and stuttering. The two factors selected for study were the phase relationship of the alpha waves and the amount of unilateral blocking of the alpha rhythm on the two sides of the head.

Subjects

The subjects for this study were 65 normal children ranging in age from 5 to 16 years and two male adult stutterers. Of the children 48 were righthanded, 8 left handed and 9 ambidextrous on the basis of a laterality index consisting of questions concerning the following unilateral activities: eating, writing, throwing, batting, combing hair, brushing teeth, sewing, reaching, cutting with scissors, hammering and shooting. Each child was asked to demonstrate how he did these things and was asked to try to think of any activities in which he did not use the generally preferred hand consistently. Only those who showed a completely right or left hand preference were classified in these groups, whereas the ambidextrous group consisted of individuals whose hand preference was definitely mixed. Eyedness or ocular preference was determined by five trials with the Miles V-Scope. Only those who showed a consistent performance in all trials were classified as right or left eyed.

Of the two stutterers, subject A was 25 years of age and had a marked stuttering defect consisting of tonic and clonic spasms both with and without speech. He repeated initial letters and syllables and sometimes whole words or parts of sentences, but the most outstanding thing was the frequent occurrence of complete blocks of the tonic type. Usually during the blocks there was no sound production except the occasional interjection and prolongation of an 'm' sound. This was often followed by a slight clicking sound made with the tongue which apparently served as a distraction mechanism. Subject B was 23 years of age. His stuttering was much less severe and consisted chiefly of the repetition of initial letters and frequent mo-

mentary blocking during which an 'ah' sound was often introduced. Occasionally there were long blocks during which no sound was uttered. Both subjects showed some degree of mixed laterality.

Apparatus and Procedure

Details of the apparatus and procedure are given in an earlier publication (4). Briefly, the amplifying and recording system consisted of two matched and independent amplifiers of suitable characteristics and a Westinghouse type PA oscillograph. All recording was on photographic paper, usually driven at a speed of 8 cm or more per second. Except for the more recent experiments in which small, silver chlorided, silver hat electrodes were attached to the head by means of collodion, the electrodes used during the major part of the study consisted of small gold discs sunk in bakelite blocks and filled with an electrode jelly. These were attached to the head by means of bandages.

For the occipital records a pair of electrodes was placed over each occipital region in symmetrical positions. The bipolar recording method was followed and the electrodes of each pair were 5 cm apart in a line parallel with, but 5 cm lateral to the mid-line. The most anterior electrode was just behind the parieto-occipital fossa. In recording from the motor speech area of the stutterers the electrodes were 5 cm apart but along the line of the central sulcus on the lateral surface of the head. Chiene's method (3) for determining the relationship between cranio-cerebral topography was used for calculating the approximate position of the motor speech area.

During the recording the subjects sat comfortably and quietly in a dark and relatively sound-proof room with eyes open. A series of records was taken at random intervals during a 15 to 30 minute period after the subject had become adapted to the situation. In the case of the stutterers records were obtained during silence (sitting quietly at rest) and during speech which was picked up by a microphone and recorded on a separate voice line of the oscillograph record. The voice line was later labelled with the exact speech sounds produced, either from shorthand notes or a dictaphone record simultaneously obtained. This made possible the correlation of the brain potential record with the simultaneously recorded speech record and permitted the identification of the periods of blocking and stuttering speech. In some records no attempt was made to record the speech, but the stuttering periods were signalled by an observer. The signal in such cases was a condenser discharge appearing as a sharp spike-like deflection on either the time or voice line.

Analysis of Records.—The phase relationship of the alpha waves in the records from the two hemispheres was determined by placing a celluloid ruler at right angles to the edge of the recording paper and comparing the peak of a wave in the lower record from the right side of the head with the wave directly above it from the other side of the head. If the peak of the wave below deviated to the right or left of the peak of the wave above by more than half of the duration from peak to trough of the upper wave the relationship was considered asynchronous or out of phase. The percent of waves in the total record in which asynchronous relationships obtained was determined.

Unilateral blocking was defined as the absence of alpha waves on either side of the head while the rhythm on the other side was distinctly present. If blocking occurred simultaneously in both hemispheres, as it frequently does during stimulation or spontaneous remissions, it was not included in the percent of unilateral blocking for the right and left sides of the head. Thus in this respect the amount of unilateral

blocking is a distinctly different measure from one which takes into account the total percent of time that an alpha rhythm is present or absent.

Examples of out-of-phase relationships between the alpha waves of the two hemispheres as well as occasional periods of unilateral blocking are indicated in Fig. 1 which shows simultaneous bilateral occipital records from four normal subjects.

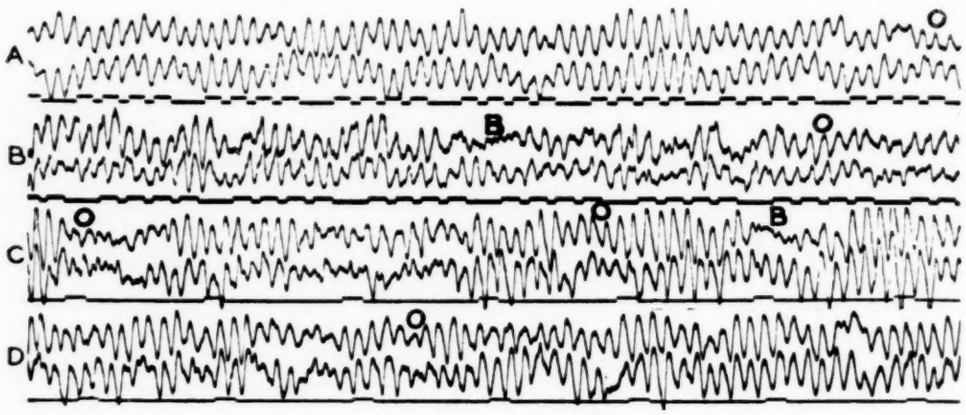

FIG. 1. Records of brain potentials simultaneously recorded from the right (lower line) and left occipital regions of four normal subjects showing alpha waves out of phase in the two hemispheres at points marked (*O*) and unilateral blocking of the alpha rhythm marked (*B*). Time is shown in seconds at the bottom of each record.

RESULTS

Phase Relationship and Laterality.—The mean percent of out-of-phase relationships between the alpha waves of the right and left occipital regions in lefthanded, righthanded, and ambidextrous subjects are shown in Table I. Also given in this table are the data for the right and lefthanded groups when further sub-divided on the basis of eyedness. The mean percent of out-of-phase relationships for the righthanded group (11.8 percent) is less than for either the lefthanded (16.3 percent) or the ambidextrous (22.3 percent) groups. As will be noted from the critical ratios and the chances in 100 that the true difference is greater than zero, only the difference between the righthanded and ambidextrous groups is highly significant. However, when the mean of the righthanded-right eyed group (8.6 percent) is compared with the means for the ambidextrous (22.3 percent) and the lefthanded-right eyed (16.9 percent) groups the significance of all differences is increased.

In general then it may be said that there is less asynchronous activity in the two cerebral hemispheres in individuals

TABLE I

PERCENT OF WAVES OUT OF PHASE IN THE TWO CEREBRAL HEMISPHERES

Laterality	No. Subj.	Mean Percent	S.D.	Significance of Mean Diff.	
				C.R.	Chances in 100
Lefthanded.....	8	16.3	7.33		
				1.45	92.6
Righthanded.....	48	11.8	6.48		
				3.46	99.9
Ambidextrous.....	9	22.3	7.63		
				4.29	99.9
Right-right Eyed ..	37	8.6	8.22		
				2.26	98.8
Left-right Eyed ...	7	16.9	7.62		

PERCENT OF UNILATERAL BLOCKING IN THE TWO CEREBRAL HEMISPHERES

Laterality	No. Subj.	Mean Percent	S.D.	Significance of Mean Diff.	
				C.R.	Chances in 100
Lefthanded.....	8	3.6	2.20		
				1.14	87.2
Righthanded.....	45	2.2	2.31		
				0.36	64.0
Ambidextrous.....	8	2.7	3.22		
				0.48	68.4
Right-right Eyed ..	37	2.0	3.40		
				1.63	94.8
Left-right Eyed ...	7	3.9	2.27		

who show a high degree of laterality than in those who lack a definite and complete laterality. The possible implications of these results will be taken up in the discussion after data from the stutterers have been presented.

Unilateral Blocking of Alpha Waves and Laterality.—For the righthanded group the mean percent of unilateral blocking on the left (1.3 percent) was slightly greater than on the right (0.9 percent), while for the lefthanded group the blocking was slightly greater on the right (1.9 percent) than on the left (1.7 percent). The differences in the percent of blocking on the two sides of the head in these two groups are not significant. Although in most individuals the blocking tended to be confined to one hemisphere, it was found that the number of individuals showing more blocking on the right or more on

the left was about equal in both groups. Thus the differences in the amount of unilateral blocking on the two sides of the head are not great enough to be of value in differentiating the two hemispheres in relation to laterality.

The total amount of blocking that occurs in both hemispheres in the various groups is shown in Table I. From the critical ratios it will be observed that the differences between the groups are not significant. However, in agreement with the data on phase relationships, the righthanded group shows the least blocking. A rank difference correlation between the total amount of unilateral blocking and the degree of asynchronism for the entire group of subjects showed a low positive correlation of 0.28, but for a few individuals who showed a high degree of asynchronism there was also a fairly high degree of blocking.

Phase Relationships and Unilateral Blocking in Stutterers.—The alpha rhythm in the occipital regions of both stutterers was very rhythmic and regular and almost continuous which made determinations of phase relationship and unilateral blocking highly reliable. Because of the greater irregularity of motor area records they were somewhat less reliable. Four series of experiments were carried out with subject A during a period of two months and each time the results were very consistent. Subject B was studied during only one experimental session.

The results of the analysis of the records obtained during all periods of study are shown in Table II. The mean percent of out-of-phase relationships for all control periods without speech for subject A was 22.2 percent in the occipital region and 20.5 percent in the motor speech area. Although during propositional and repetitive speech these values dropped slightly in both regions the changes from silence to speech were not significant. The mean percent of asynchronism for subject B during the control period was 16.6 percent in the occipital and 23.1 percent in the motor speech area. During propositional speech there was no significant change in these values. In general then it may be said that there is no significant or consistent change in the out-of-phase rela-

TABLE II

	Percent Out of Phase		Percent of Unilateral Blocking					
			Occipital			Motor		
	Occipital Region	Motor Region	Right	Left	Total	Right	Left	Total
Subject A								
Control: No speech....	22.2	20.5	0.0	1.3	1.3	0.0	7.8	7.8
Propositional speech.....	19.9	14.9	3.3	6.5	9.9	1.8	16.3	18.1
Repetitive speech.....	16.6		0.7	7.4	8.1			
Subject B								
Control: No speech....	16.6	23.1	2.9	0.7	3.6	6.9	0.9	7.8
Propositional speech.....	19.2	24.4	2.5	0.0	2.5	9.8	2.5	12.3

tionships during silence and speech in these two stutterers. It is important to note, however, that the percent of asynchronism in occipital and motor regions for both subjects is quite high and approaches the mean value reported for the ambidextrous group of children.

It is interesting to note that during silence unilateral blocking occurred only in the left hemisphere of subject A, being 1.3 percent in the occipital region and 7.8 percent in the motor speech area. During propositional and repetitive speech the amount of blocking in both occipital and motor speech areas increased markedly, and again the blocking was chiefly confined to the left hemisphere. Subject B on the other hand showed blocking mainly in the right hemisphere. During propositional speech the blocking again predominated on the right and was increased in the motor speech area but not in the occipital region.

These results may be summarized as follows: In both subjects there is some evidence of ambilaterality and in both a fairly high degree of asynchronism of the alpha waves of the two hemispheres. There was no consistent change in the amount of asynchronism during periods of silence and speech, but in both subjects the amount of unilateral blocking was increased during speech, particularly in the motor speech

areas. It is perhaps significant that the blocking in both stutterers is chiefly confined to opposite hemispheres, but the possible relationship of this differentiation to laterality cannot be demonstrated at present.

Perhaps more important for our consideration here is the association of phase reversals and unilateral blocking in the two hemispheres of the stutterers with actual stuttering spasms or blocks. Sample records of the bilaterally recorded occipital alpha rhythms in subject A during silence and speech are shown in Fig. 2. Record A was obtained during

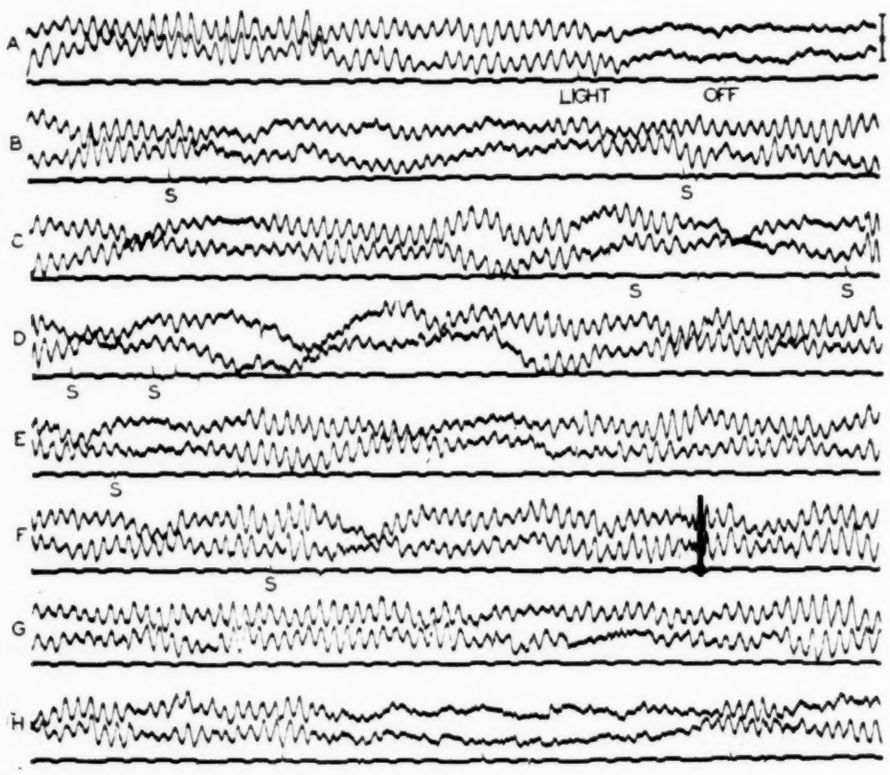

FIG. 2. Simultaneously recorded brain potentials from right and left occipital regions of a stuttering subject during silence (record *A*) and during propositional speech (records *B* to *H*). Stuttering episodes marked *S*. See text for explanation.

a control period of silence and shows the rhythmic alpha waves from the two hemispheres. The waves are completely out of phase during the first second but thereafter are perfectly synchronized until abolished by a light stimulus. Records B to H show the bilateral occipital alpha rhythms during propositional speech. Stuttering spasms or blocks were signalled by an observer and are marked under each record by

the letter S. Usually just prior to each of the marked stuttering periods there is an interval during which the alpha waves of the two hemispheres are completely reversed in phase. Also during or just prior to some of the stuttering spasms there are unilateral blocks of the alpha rhythm. One of these unilateral blocks occurs in the left hemisphere (upper line) of record C and another in the right hemisphere (lower line) of record G when unaccompanied by stuttering signals. This may mean that no speech was in progress at the moment or that the observer was unable to distinguish or record all speech blocks. In record H there is a prolonged blocking of the alpha rhythm in both hemispheres which occurred during a prolonged stuttering block as is shown by the three series of signals marked on the time line.

More sample records are shown in Fig. 3. Record A during a control period without speech shows the waves mainly synchronized but occasionally getting out of phase. In record B the subject was asked to say 'father' immediately

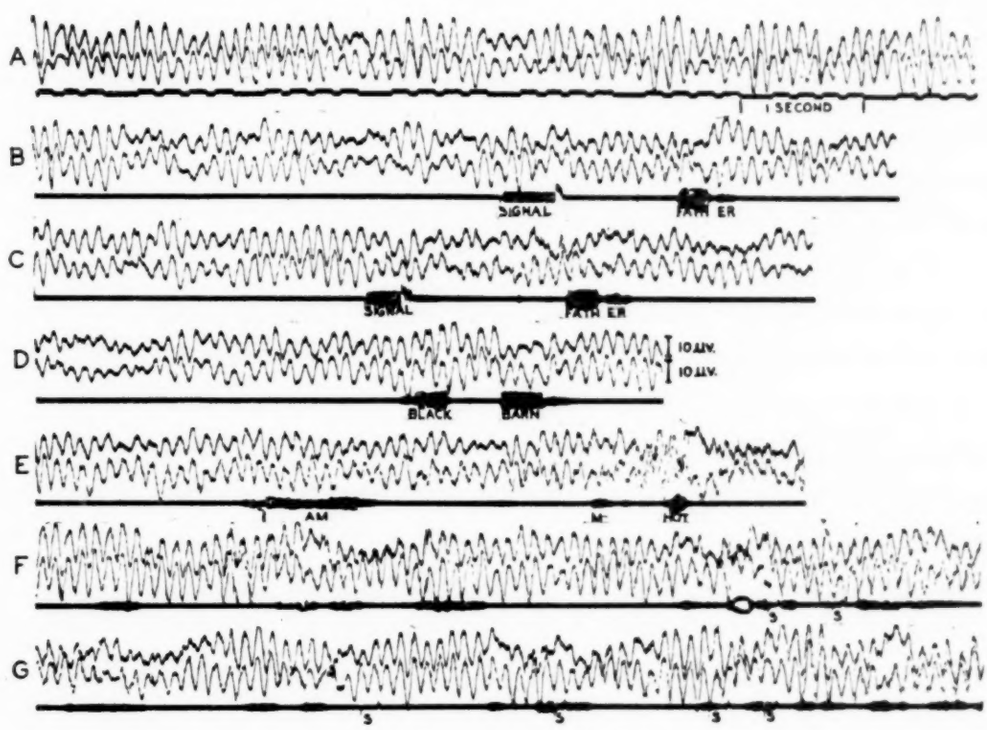

FIG. 3. Bilateral occipital brain potentials in a stutterer during a control period without speech (*A*), during repetitive speech upon signal or command (*B* to *E*), and during propositional speech (*F* and *G*). See text for explanation of phase reversals and blocking.

upon hearing a weak buzzer signal. After the usual tongue clicking habit indicated by a brief deflection of the voice line and underlined by a dash, the word 'father' was said without difficulty and it will be noted that the alpha waves are perfectly in phase throughout and show no evidence of blocking.

In record C the subject had some difficulty producing the word 'father' after a signal and it will be noted that immediately after the signal the waves in the two hemispheres were reversed in phase. 'Black barn' was produced in record D without difficulty and there is no evidence of reversals of phase or unilateral blocking. In record E the subject was asked to say "I am hot." As indicated by the voice line the first two words came easily enough and were accompanied by synchronous brain waves but there was a distinct delay and blocking in producing the word 'hot.' During the blocking interval the subject made an 'm' sound and clicked his tongue (indicated by dash). At the approximate time during the blocking period when the word 'hot' should have been produced for continuity of speech the alpha waves were reversed in phase and partially blocked on the left. In records F and G during propositional speech the stuttering periods are marked by the letter S, and preceding each of these periods it will be noted that there are either complete reversals in phase, unilateral blocking or both.

Figure 4 shows still more samples from the right and left occipital areas. Record A was obtained during a control period without speech. Records B and C were obtained while the subject was trying to say "The weather is becoming very hot." The speech was picked up by a microphone and recorded on the voice line; the voice line deflections were then labelled with the exact sound productions. Throughout these two records the subject was blocking and repeating. Associated with these periods are intervals of reversal of phase and very obvious periods of unilateral blocking, particularly in the left occipital record. In the first part of record D the subject was asked to repeat over and over the words 'one-two,' an automatic repetitive type of speech. Above the second 'one-two,' the waves are reversed in phase and a block

occurs in the left hemisphere. Immediately following this and apparently as a consequence of it the next 'one' was blocked and repeated. In the latter part of D the subject was asked to continue the progression, 'one-two-one, one-two-two, one-two-three,' etc., which he did successfully without blocking or phase reversals of the brain potential records until the end of E where he blocked and repeated 'six' and where a distinct left unilateral blocking of the alpha rhythm occurred with also some phase reversals.

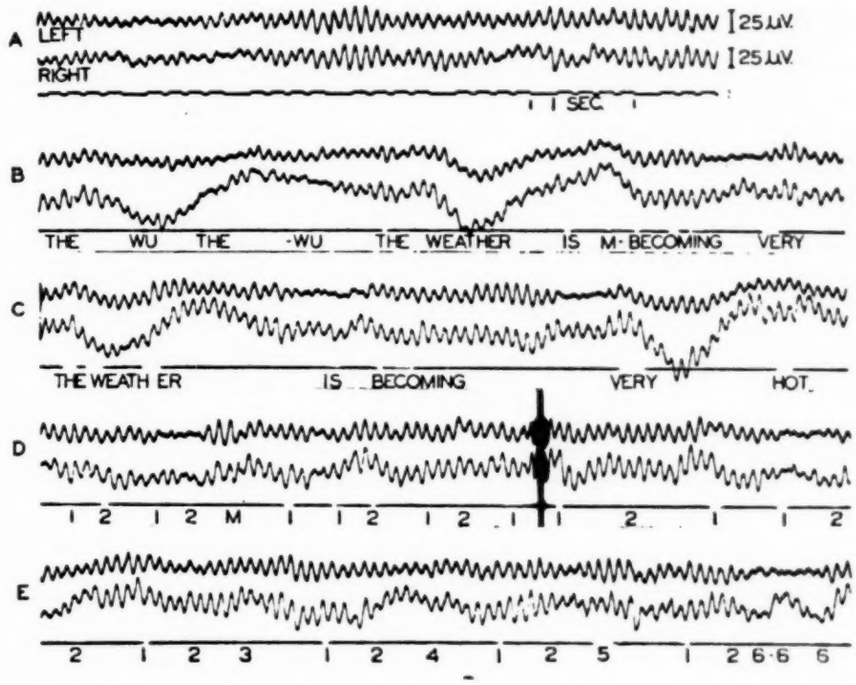
A
LEFT
RIGHT
25 μV.
25 μV.
1 SEC.
B
THE WU THE -WU THE WEATHER IS M-BECOMING VERY
C
THE WEATH ER IS BECOMING VERY HOT.
D
1 2 1 2 M 1 1 2 1 2 1 1 2 1 1 2
E
2 1 2 3 1 2 4 1 2 5 1 2 6 6 5

FIG. 4. Right and left occipital brain potentials in a stutterer during silence (*A*) and during speech (*B* to *E*) in which stuttering repetitions and blocks occur. See text for description.

Finally Fig. 5 shows records of bilateral occipital electroencephalograms (A to D) and bilateral motor speech area records (E and F). Records A and B are during propositional speech. Preceding the stuttering signal (S) in record A the waves were reversed in phase; in record B there was a block in the left occipital region and the waves were reversed in phase preceding the stuttering signal. The subject said, "I see a brown bear" during record C without difficulty and there are no evidences of phase reversal or blocking. In the last half of record C and in record D the subject responded

to a question concerning the color of his mother's hair. His answer was given with considerable difficulty and blocking as is evidenced by the labelled voice record. During the periods of greatest delay and blocking in the speech there were frequent phase reversals and partial blocking of the alpha rhythm particularly in the left occipital record. Records from the right and left motor speech areas are shown in E and F. The first half of E was during a control period with-

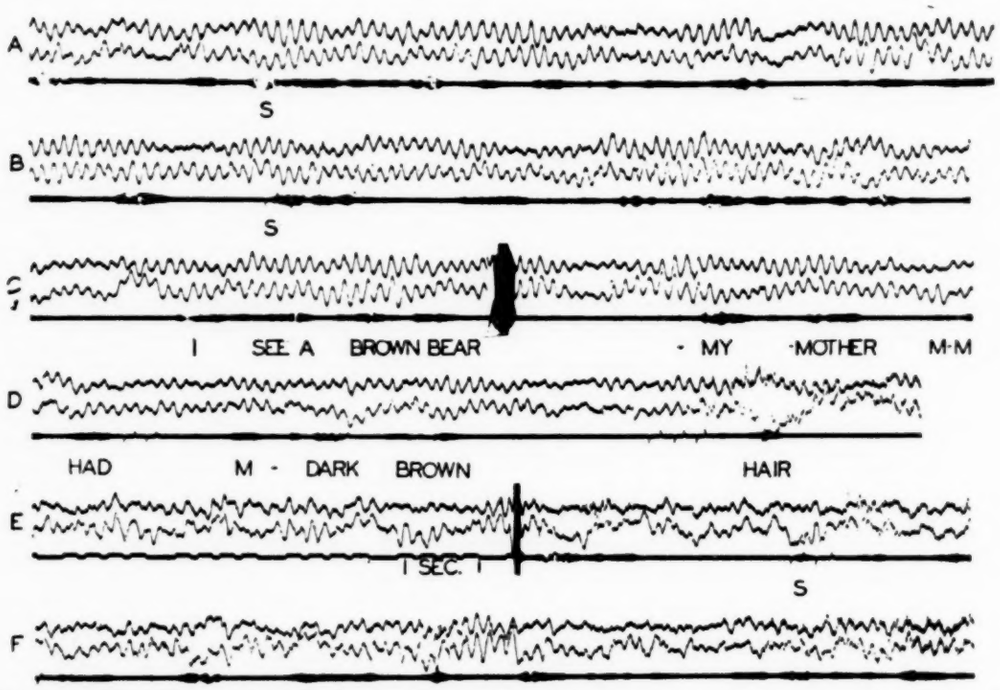

FIG. 5. Records *A* to *D* from bilateral occipital regions in a stuttering subject. Records *E* and *F* from motor speech areas. See text for description of records.

out speech, the last half of E and record F during propositional speech in which only one stuttering period was signalled. Because of the greater irregularity of motor area records the asynchronous and blocking intervals are more difficult to observe.

In summary it may be said that practically all of the signalled or recorded stuttering episodes in which a blocking of speech was involved were accompanied by unilateral blocking (sometimes bilateral blocking) or phase reversals of the alpha rhythm in the occipital and motor speech regions.

DISCUSSION

The results reported here indicate that there is a higher degree of asynchronism of alpha waves in the occipital regions

of the two cerebral hemispheres in individuals with mixed or indefinite laterality than in those who show a complete (*e.g.*, righthanded and right eyed) laterality. The results also show that in two stutterers there was a degree of asynchronism of alpha waves in the two hemispheres comparable to that of the ambidextrous or mixed laterality groups. An examination of the brain potential records of the stutterers has revealed a consistent association of bilaterally asynchronous alpha waves (in both occipital and motor regions) with stuttering periods. This suggests that the existence of out-of-phase relationships of the alpha waves in the two cerebral hemispheres may interfere with the formulation and expression of speech, and that the incidence of such interference is apt to be greater in those individuals who lack definite and complete laterality.

Another factor, the amount of unilateral blocking of the alpha rhythm in one hemisphere or the other, seems also to be related to stuttering episodes. Unilateral blocking of the alpha waves was slightly greater in the groups lacking laterality but the difference in the amount of blocking in the two hemispheres was not sufficiently significant to differentiate them in terms of laterality. However, in both stutterers unilateral blocking, which was significantly increased during speech, was chiefly and consistently confined to one hemisphere, although on the right in one and the left in the other stutterer.

The most that can be said at present concerning these findings is that both the asynchronism of alpha waves in the two cerebral hemispheres and the unilateral blocking of the alpha waves in one or possibly both of the hemispheres are related to stuttering and that the asynchronism and possibly the unilateral blocking are related to ambidexterity or the lack of a definitely expressed laterality of motor function.

It is not entirely clear what causes the conditions of asynchronism or blocking or just how they are related to stuttering and the lack of laterality. However, so far as stuttering is concerned it seems reasonable to suggest the following hypothesis. In order for bilaterally paired speech muscles to work together in a synchronous manner to produce well regulated speech sounds, motor impulses from the respective con-

tralateral hemispheres must reach them almost simultaneously. Therefore, the impulses must arise simultaneously in the motor areas involved. This necessitates a common state of readiness to respond or a common level of excitability in the motor areas of the two hemispheres. If one considers that the successive peaks and troughs of alpha waves from a particular region of the cortex represent alternations in the excitatory state of the cortex or its susceptibility to excitation (as has been suggested by Bishop (1)) then asynchronism of the alpha waves in bilaterally homologous regions of the cortex implies that impulses cannot arise simultaneously in these regions. This would also apply to the regions of the cortex (visual and auditory) involved in preliminary states of organization of speech patterns as well as to the motor speech areas, for such patterns must be transmitted to the final common outlet in the motor speech areas.

Finally, there is some evidence (2) (1) that the alpha rhythms of the cortex are controlled or regulated by means of 'loop circuits' extending from the thalamus to the cortex. Thus it may be that bilateral controlling centers in the thalamus are subject to the influence of sensory and emotional stimulation in relatively unequal ways which cause asynchronism and blocking of the alpha waves in the cortex, or perhaps the physiological state of homologous regions of the cortical hemispheres differs in its response to subcortical timing or regulating influences. In any event the appearance of out-of-phase relationships or unilateral blocking implies that homologous areas of the two hemispheres cannot function synchronously.

Although there are differences in the phase relationships of the two hemispheres and in the amount of unilateral blocking, which appear to be related to stuttering and laterality, neither of these factors selectively differentiates the hemispheres in terms of 'dominance.'

Summary

An analysis of brain potential records simultaneously obtained from the right and left occipital regions in 48 right-handed, 8 lefthanded and 9 ambidextrous children has re-

vealed that the alpha waves in the two hemispheres are out of phase a greater percent of the time in ambidextrous and lefthanded subjects than in righthanded subjects; also that there is less unilateral blocking in the righthanded group. Unilateral blocking was slightly greater in the left hemisphere for the righthanded group and in the right hemisphere for the lefthanded group but the differences were not significant enough to permit of differentiation between the hemispheres in terms of 'dominance' or laterality.

The records from two stutterers showed a degree of asynchronism comparable to that of the ambidextrous or mixed laterality groups. The percent of asynchronism did not change consistently or significantly during speech. Unilateral blocking of the alpha waves was increased during speech. Preceding almost every recorded stuttering episode there were periods of asynchronism of the alpha waves in the two hemispheres (in both occipital and motor speech areas) as well as frequent periods of unilateral blocking of the alpha rhythm. This led to the conclusion that asynchronism and blocking of the alpha rhythm in the two cerebral hemispheres may interfere with the formulation and expression of speech. Therefore the higher degree of asynchronism and blocking in individuals lacking a definite and complete laterality is apt to make their spech more subject to interference.

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STUDIES IN HIGH SPEED CONTINUOUS WORK: IV. MOTIVATION AND HEDONIC TONE

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When work must be done continuously for some time at maximum possible speed there are a number of subjective factors which cause wide and rapid variations in efficiency. The term subjective factor is here rather loosely applied to those circumstances of the experiment which seem to arise from S himself; they are chiefly mental, though some, *e.g.*, blocking and pain, may have a physical component.

Thus, for instance, motivation is an important subjective factor. Unfortunately it changes considerably in the course of the performance, and often is relegated to a quasi-passive rôle in the background as a set that lasts to the end of the task. The hedonic tone, the amount of pleasantness or unpleasantness felt during the performance, varies too; and while it is doubtful whether taken by and large it has any major effect on the performance of the task, it certainly is the source of minor, rapid fluctuations in efficiency. The subjective side of fatigue (the feeling of tiredness), pain and blocking, irritate and discourage S and lower his hedonic tone and often his efficiency.

So interlinked are all these components of the general subjective feeling that it is exceedingly difficult to partial out the effects of any one. Naturally the initial motivation—the set, as it were, pitches the key for the hedonic tone, whose melody covers a range which is in part determined by S's success in the task, the actual discomfort experienced, and the freedom from distractions and variations in efficiency such as are occasioned by blocking. The social setting is of great importance, but it has not been especially studied in this experiment. Rather than to attempt to single out the effect of any one factor it is much easier to ascertain in a rough way the total effects of all. In this paper we will deal with the sub-

jective factors that affect continuous work at high speeds, and specifically we will treat of motivation and hedonic tone, and in another paper, of feelings of tiredness, blocking and pain.

Other papers have described the experiment and the task (1, 2). Suffice it to say that in experiment A, 12 Ss, and in experiment B, 2 Ss, worked for 6 hours or more at a tapping task; in the former case, with few or no interruptions, and in the second, with one minute rest every ten minutes. While Ss worked Es took their tapping rate every minute, jotted down all remarks and circumstances affecting the experiment, and in a number of cases called at stated intervals for a rating on a previously agreed hedonic scale. At the conclusion of the work period S wrote out a fairly lengthy introspective account of his feelings during the course of the experiment, sometimes using notes made by Es to guide him. The findings of this paper are based chiefly on Es' notes and Ss' introspective accounts as correlated with the tapping scores.

Motivation

Competent Ss who are willing to undertake an experiment in continuous work are not easy to find, due to the length of time they must devote to the experiment and the monotony of the task. Often the only satisfactory way seems to be to hire Ss, and sometimes a system of bonusing is worked out to ensure continuous maximum effort, as was done by Phillips (3) and Flügel (4). Ss in the experiment here reported, though all unpaid volunteers, were nevertheless strongly motivated. The work was done as a project to which were assigned a considerable part of the term marks in a senior course in psychology. Only those willing and eager to work till exhaustion set in were chosen, and they were informed that it would take from 6 to 7 hours' work at least. It was felt that the eagerness of Ss, their desire to make a good term mark, and the scientific spirit which they manifested would prove adequate to elicit maximum effort in an experiment calling for courage and constancy. Preliminary experiments had given rise to the hope that careful selection might produce excellent Ss; certainly the results showed that this confidence

was not misplaced. The author wishes to express his gratitude to and admiration of Ss who in spite of monotony, actual physical pain and discomfort gave their best during the long hours of the experiment and coöperated in every possible way.[1]

Actually there were other motives probably just as powerful operating at the outset of the experiment; a keen spirit of rivalry, pride in one's endurance, curiosity to see whether one had the requisite fortitude, and the exhilaration of noting during the course of the experiment the increase of one's working rate after long hours, played a large rôle, as may be determined from the introspective remarks of Ss.

This experiment took place in a social setting: two Es in each group had already taken part as Ss or were going to do so. Besides, the author of this paper, the instructor of the course, was in almost constant attendance. It was impossible for brief intervals to avoid the presence of onlookers, whose obvious yet discreet admiration at the effort shown was conveyed to Ss. Whenever the minute readings declined near the predetermined basal rate, Es attempted by warnings and verbal encouragement to maintain S's efficiency. No small motivation came from a knowledge of the results, which were sometimes given directly to Ss, or which at any rate, they became accustomed to judge with a surprising degree of accuracy.

Towards the end of the working period another motivating force proved very strong indeed. When the working rate went below the predetermined basal rate Ss were given a rest. They soon found that this rest stiffened them considerably and that it required an extra amount of energy and determination to resume the task—often it involved no small amount of physical pain. Rather than suffer these effects of an enforced rest Ss often struggled to avoid the rest by maintaining their efficiency.

The motivation was complex indeed, and of course varied from S to S; but it was surprisingly strong. As the end

[1] The following students acted as Ss: Messrs. Allen, Cairns, Carson, Charyk, Cruickshank, Ewasiuk, Ferguson, Gaboury, Gogek, Hall, Kieryluk, Morgan, Thompson, Williams.

approached the prospect of relief seemed to be the most urgent of all motives, sufficient in nearly every case to evoke a long continued spurt.

Introspective Comments

Excerpts from the comments of Ss will serve to substantiate the statements made in regard to the motivating factors.

S9.

Since I was the first of our group to take the task and had little or no idea how it would effect me, I approached it with some apprehension. I felt determined however to prove to myself that I could maintain a high efficiency during the work.

S6.

I started the task with some inward doubt as to my ability to carry it to a successful conclusion. By successful conclusion I mean the continuance of performance until I had exceeded, or at least equalled, the endurance of my predecessors, and produced comparable results.

S7.

Before beginning the test, I had very little hope of lasting much longer than an hour. According to my previous trial test of ten minutes, I had a maximum speed of 214 taps per min. This discouraged me somewhat. However with this and the idea that I must last six or seven hours I resolved to apply the acid test, so to speak.

S3.

Just prior to the beginning of the test my mental attitude was one of determination. Motivations were twofold:

1. Rewards—
   - (*a*) Interest in the experiment itself, hoping that satisfactory results would be forthcoming.
   - (*b*) Substantial prize of marks on term work.
2. Personal satisfactions—
   - (*a*) Hoping that I could 'take it.'
   - (*b*) Hoping that I could keep up and do as well as my colleagues.

I had already observed for two Ss, and was rather fed up with this task. The test, therefore, was somewhat welcomed, as a contrast to the monotony of observing.

I believe that I am correct in saying that both previous Ss in our group (S1 and S12) had experienced, in the test, an afternoon of suffering and a good deal of fatigue. In all, I was led to believe that I was in for an afternoon of torture. While I did not relish this prospect, nevertheless it was deemed expedient by myself to undergo the rigors of what might be a very unpleasant six or seven hours. In short, while I believed I was due for some suffering, I none the less entered the test with a good deal of determination, pledging to do my best, and hoping for some results that would justify the effort involved.

S8.

Having weak eyes, the constant movement of my arm gave me a headache and I had a good notion to end the ordeal, but since my co-workers thought that I could not better their endurance record, I continued until I had bettered their record by at least five minutes. This gave me a great satisfaction to see the disappointments in their faces, so I even beset them with an end spurt of over 300 taps.

Typical of the comments on the effects of social stimuli are the following:

S12.

I noted the effect of social stimulus, perhaps caused by a desire to excel, or the natural feelings that come out in us due to good companionship. When told to speed up I invariably did a little better than I otherwise would have done.

S8.

Three times during the course of the experiment, students entered the psychology laboratory and tried to decipher what we were doing. This made me self-conscious, and I strived to increase the number of taps per min. and every time I succeeded in raising the level to away over 300 taps.

S4.

A janitor entered to inquire how we had got in and left with the threat that he was going to make inquiries. During his presence I explained to him why we were there and before I turned my attention back to the tapping I had dropped, momentarily, to my lowest figure in the first four hours. Incensed at this and at the janitor I rose to a 220 tap level which was well maintained for two hours. Better work, the continued absence of any great fatigue effect both raised my spirits to a higher pitch and determined me to set a record for this kind of experiment.

Hedonic Tone

During the experiment a favorable opportunity offered itself to determine whether the progress of the hedonic tone followed the same course as was observed by Thorndike (**5**), Poffenberger (**6**), and others. The work in this study was generally speaking of a more strenuous nature, causing considerable physiological fatigue, often involving not merely discomfort but real physical pain, and lasted longer, than most of the experiments on hedonic tone. As the work progressed Es frequently demanded from S a rating on a previously determined scale of degrees of pleasantness. Cognizance was taken of the difficulty described by previous workers, chiefly by Poffenberger (**6**), who wrote: "An evaluation of feelings in this scale is subject to all the errors commonly noted in such ratings, plus those which may be due to the elusive experiences which are to be rated. One cannot equate the meaning of 'very tired' among the different Ss, although there is reason for believing that the scale was a fairly constant one for any given S."

The scale used ranged from 0 to 10, with 5 the indifference point, and 10, the point of maximum satisfaction. Scale values were obtained from four working groups, and from 9

of the 14 Ss of Experiments A and B. Though the scale values varied somewhat from group to group they were fairly constant in their meaning within the group; probably they should be thought of as individual in character, and hence only the trend of the values, rather than the absolute value, except as being above or below the indifference point, is of significance. Table I gives the identity of S and the number

TABLE I

RATINGS OF HEDONIC TONE

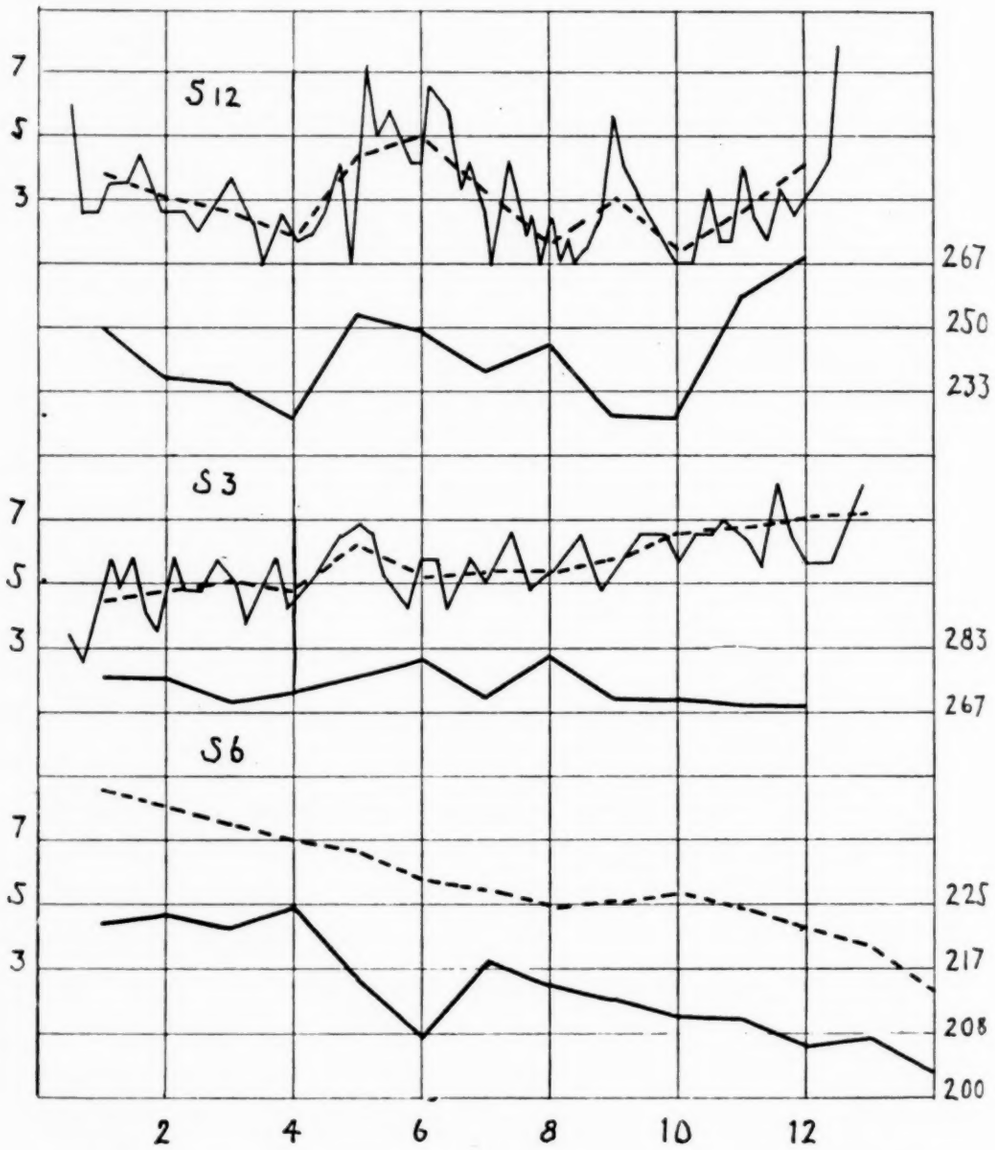
S	No. of Ratings	Average Time between Ratings	Average Rating
2	24	15.0	5.1
3	51	7.6	5.8
4	26	16.2	5.3
6	31	13.5	5.6
8	31	13.5	6.1
10	24	15.0	6.0
12	63	5.7	2.7
13	34	10.0	5.1
14	34	10.0	5.2

of ratings made, together with the average time between ratings. The relatively large number of ratings made by Ss 3 and 12, who belonged to the same working group, necessitated taking an average for comparison purposes with the half hour working rates. The figure gives for S3 and S12, not only the average rating per half hour, but also the individual ratings. The half hour working rates are also recorded on the figure.

Graphs of the hedonic rating and the working rate were made for all Ss, but are not all shown here. A continuous drop in hedonic tone, similar to that found by Poffenberger and Thorndike, was shown by Ss 2, 4, 6 and 8; the graph of S6 shown in the figure is typical of these curves. Ss 10, 13 and 14 varied in hedonic tone on both sides of the indifference point, and their deviations were as often as not in opposite directions. Their curves are not shown in the figure, but those of S3 and S12 are presented, as being of unusual nature.

S12 suffered a good deal of pain during the experiment, as he worked for hours under the handicap of a skinned finger

and a tender and inflamed fore-arm. As a consequence during most of the task his feelings were decidedly unpleasant. He enjoyed pleasant feelings for brief periods only;—at the be-



Relationship between hedonic tone and output. Light line: hedonic tone ratings as frequently given. Dotted line: hedonic tone ratings averaged per half hour. Heavy line: half hour averages of tapping rate. Ordinates at left: ratings on hedonic tone scale. Ordinates at right: number of taps per minute. Abscissæ: number of half hour periods.

ginning before the pain was felt, towards the middle of the task when he was becoming endured to the pain, and when the end was approaching. To be noted are the violent oscillations of his hedonic tone, which often changed abruptly within

the five minutes which was the average time of his rating, from 2 to 7 points on the scale.

On the other hand S3 had pleasant feelings during most of the experiment and only on few occasions chiefly at the outset did he feel really unpleasant. Yet he also suffered pain, though it was much milder in his case than was that of S12. The oscillations of hedonic tone in his case are slight, and the tone rises continuously from the beginning, in spite of pain and fatigue. Two explanations may account for this: first, his delight at doing so well, at exceeding his companions and at suffering less than they did in spite of his slenderer physique; and, secondly, his interpretation of hedonic tone probably differed from that of the other Ss. While they were more prone to judge their feelings objectively, in the sense given by Phelan (**7**) and to focus their attention on the pain, discomfort and fatigue they experienced, his ratings were more subjective, and stressed the delight he was experiencing in his success. However it must be borne in mind that the other Ss also took from time to time a subjective viewpoint, but not as constantly nor to the same degree as he did.

It is important to note that most of the Ss varied from the pattern of the hedonic tone given by Poffenberger and Thorndike. Robinson (**8**), basing his inferences on the work of Yochelson and others, claims that Thorndike has perhaps oversimplified the point, and certainly the figure here given confirms that view. The feelings of 4 Ss do fall almost continuously from the beginning, that of one S rises from the very outset, and the remaining 4 Ss show a considerable variation in the course of their hedonic tone.

A more striking divergence from the findings of most previous workers is the close correspondence between the output and the hedonic tone. When the half hour averages of both output and hedonic tone are plotted for all Ss, no matter what the pattern of their curve of feelings, it is seen that the hedonic tone is more prone to follow the course of the output than it is to diverge from it. Cf. Barmack (**9**). Ss 2, 4, 6, and 8 dropped slowly but steadily from the outset in both factors, although their course was quite irregular. S3 rose

steadily in hedonic tone, while his output showed hardly any decrement, in fact it rose for the first four hours.

The long term concomitance between the two factors was unexpected and was not clearly felt by Ss themselves. They did however in general perceive that rapid changes in hedonic tone, chiefly as a result of brief periods of pain, cramping or blocking, were accompanied by lower output; and freedom from such disturbing factors was accompanied by increased output, with consequent brighter and more encouraging feelings. When the tapping rates are correlated with the hedonic ratings for the precise minute when the latter are taken, the product moment values are $r = 0.91 \pm 0.02$ for S3 and $r = 0.31 \pm 0.08$ for S12. These Ss were the only ones from whom a sufficient number of ratings was obtained to yield reliable results.

The discrepancy between the two correlation values is to be explained in part by the fact that S12 suffered so much that, when his tapping rate dropped close to the predetermined limit, the prospect of an approaching rest caused a marked rise in his hedonic tone in spite of his poor scores. As a consequence 6 of his 36 ratings taken under these circumstances account for most of the discrepancy. On the other hand the correlation value of 0.91 is probably higher than normal, owing to the elation of S3 and the constancy of his tapping rate.

The oscillations of hedonic tone when the individual ratings are plotted are not any greater than those of the output curve minute by minute, or even for five minute periods. Naturally the half hour averages of both output and hedonic rating are much more regular.

Ratings frequently taken show marked fluctuations which contrast with the gradual trend of the half hour ratings. As was previously suggested a rating may have two components: one, subjective, which stresses the general feeling tone and attitude to the experiment and changes slowly, generally in the direction of increased boredom; the other, objective, is determined by the more fleeting factors, such as pain, cramping, blocking, encouragement or discouragement at temporary

success or failure, and is prone to wide variations. Ratings rarely taken tend to give a cross section of the feelings of the whole period, and to yield a mean rating about which the short term ratings would have fluctuated. Frequent ratings tend to stress the hedonic tone of the moment, and hence to follow the oscillations of the rapidly varying objective factors. When several ratings are averaged these objective fluctuations are cancelled out, and the slower changing, more subjective feelings determine the rating.

Introspections on Hedonic Tone

Typical comments are as follows:

S2.

At the beginning of the experiment my feelings stood at 8, and fell to 6 when early cramps and slight arm pains took the joy out of the game. These passed off to a certain degree and I became rather pleased with myself for holding a good speed and maintaining a smoothness of swing. After the first hour, my feelings sank almost to the indifference level when the experiment took on a more serious nature due to a sore elbow. In the ten minute rest my feelings remained at about the same level. Starting into work again, a rather intense ache in my shoulder sent my feelings below the indifference point as I was cross and the recorder charged me with moaning and refusing to be amused. However I don't think I was feeling quite as badly as painted. Then followed a nine minute rest period in which I felt indifferent.

Continuing the tapping, I reached a stage where the movement was quite automatic, so I continued feeling indifferent. About 4.45, or after two and three-quarter hours of working, my shoulder began to ache, so my feeling curve goes down. Forgetting my pains, I got into perfect rhythm and a good score made me feel better. After a short rest my feelings rose above the indifference point due to a high score. For the second half of this 40 min. run, pain caused my feelings to drop, even during a rest period.

Getting back to the task, I continued to work steadily and my feelings remained slightly below the indifference point. After 5½ hours work, due to my putting forth an extra effort, they dropped again and remained low until the end of the run was reached.

The curve on the hedonic scale should perhaps fluctuate to a greater degree but looking back I cannot recall thinking the experiment very foolish, or cursing, except when the stylus cut my hand or I became very irritated; but I must admit that my humor was rather flat at the end of the six hour run.

S3.

At no time did I particularly inquire as to my minute readings, as I tapped them out. I was not particularly interested in my readings; as long as I was doing my best, they did not concern me. . . .

Blocking and pain occurred frequently in the first fifteen minutes of the first run. During this period I was quite irritable, felt rather unpleasant, and swore a number of times. This mental attitude, I believe, may be attributed to the degree of pain

and suffering due to the unusually rigorous effort to which I was subjecting my arm for the first time in quite a while.

Towards the end of the first run, the absence of pain in my arm, together with an upkeep of a fairly good rate of speed made me believe that I could 'take it.' While S1 and S12 actually suffered, I felt fine; this tended to keep me mentally alert as a cheering note coursed through my mind. I felt rather more pleasant. During this period I believe that my average speed was higher than at any previous time. However not to a great degree. . . .

During this latter part of the first run whenever I spurted dull pain, not intense, resulted in my arm. This did not affect my general rate of speed. I believe the dullness of pain is due to both physical and mental adaptation to its presence (when spurting).

I decided that the first run should be stopped at the end of 3½ hours. I could have gone on indefinitely, as my arm felt fine at the time, at the general rate I was going. In fact as the run was nearing its close I did *not* want to stop.

S9.

I received several electric shocks from the apparatus as my hands were becoming quite moist and felt a sensation of utter disgust with the apparatus, the experiment and everything in general. The students working with me were amused and after a time I began to feel similarly and ceased to work under a strain. . . .

I attempted to eat a piece of chocolate but got very little satisfaction from it. My only feeling now was of resignation and I was extremely anxious to get the experiment finished as soon as possible. I was rather tired and felt a bit concerned about getting a rest, causing me to insist on knowing when I was to stop. Finally I received the word and rested for about 11 minutes. I found myself stiffening up alarmingly and my forearm was quite swollen so that I hated to think of starting again.

When the work was recommenced after the rest it was several minutes before my arm limbered up but though it felt stiff and was rather bothersome I recall a feeling of satisfaction that it did not appreciably lower my speed. My arm continued to bother me and caused me frequently to shift my position, but I felt now that I was on the home stretch and could stand almost anything. The time seemed to go swiftly up to the last half hour when I found myself counting the minutes as they were recorded and estimating the number still to go. I felt that I could go for a much longer time but that I certainly didn't want to. I had not missed my supper up to this time at all but now I began to think of it and was impatient to finish. The last three quarters of an hour were pure misery, not because I felt tired but because my forearm had swollen and pain kept me from rising to any high speeds. This last period of work dragged much more slowly than any of the others and I received the word to stop with a great deal of relief.

S13.

The feeling of pleasantness or unpleasantness is apparently connected with physical condition and with the speed and efficiency of the tapping; in fact all three aspects seem to be interrelated. However during the first part of the experiment, although I realized the relationship between muscular aches and cramps and the accompanying work decrement, hedonic tone seemed to be more or less an isolated factor. For instance, about the four and one-half hour mark, when I was weary all over, feeling reached its maximum in half an hour and then gradually subsided into a state of indifference wherein I felt neither pleasant nor unpleasant. The maximum degree of unpleasantness, although it practically approached actual nausea, seemed to have

little effect on my rate of tapping which averaged 251.6 per minute, during that particular period of continuous work. The feeling of pleasantness was greater after about two and a half hours' work at which time the average speed was also highest, being approximately 275 taps per minute. A number of friends who were present at different times in this period increased this feeling of pleasure, and probably the fact that they were looking on stimulated me to a greater effort. It seems to me that an association between hedonic tone and speed was sufficiently below or above my average speed for me to be conscious of the fact, and accordingly depressed or cheered by it. . . .

As the experiment approached its conclusion a feeling which can better be described as 'dull relief' rather than as pleasantness came into existence. Following the experiment came a kind of emotional let-down, which persisted in the form of a heavy sense of depression (not altogether explainable by the pain which my arm was giving me), which lasted over an hour. This was probably due in part to the unusual state of fatigue. . . .

The habitual eating period was purposely neglected for an hour in my case, and seemed to have the effect of increasing rather than of decreasing my speed. . . .

When my mouth was dry, a drink of water seemed to result in a temporary increment, but at no time did I feel any desire to partake of food, the very thought being almost distasteful to me. I believe that any increment that resulted from drinking water was due to the feeling of greater pleasantness which followed it, than to any physical factors connected with the quenching of thirst. . . .

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SEMANTIC CONDITIONING INVOLVING THE GALVANIC SKIN REFLEX

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In a recent issue of *Science*, Razran [1] described the application of his salivary conditioning technique to the field of semantics. He reported success in transferring conditioned salivation from four words to a homophone and to a synonym for each of the original stimuli. In concluding the article, Razran mentioned the possibility of employing the galvanic skin reflex (GSR) as a substitute for the salivary technique. The present paper reports an initial investigation in which the words used by Razran formed the basis for a transferred conditioned response involving involuntary changes in skin resistance.

The GSR's were obtained by means of an instrument devised by F. C. Thorne in which a bucking circuit is employed to measure the changes in resistance of the subject. The amplitude of the reflex is measured in terms of microamperes. Metal electrodes were inserted in beakers filled with water into which the forefinger and the second digit of the subject's left hand were thrust. The fingers were wrapped in scotch cellulose tape for a predetermined distance in order to equalize the amount of skin exposed and to prevent shifts in resistance due to up and down movements of the fingers in the electrolyte. The stimulus words were typewritten on library cards and presented manually to the subject who was seated in a position from which the face of the instrument was not visible. Each card was exposed for five seconds during which the experimenter recorded the amplitude of the galvanic skin reaction.

The actual procedure consisted of three steps. In the first, each subject was presented with 50 stimulus words, ex-

[1] RAZRAN, G. H. S., A quantitative study of meaning by a conditioned salivary technique (semantic conditioning). *Science*, 1939, **90**, 89–90.

posed seriatim. Of these words, four were later to be conditioned to the sound of a loud buzzer. A homophone and a synonym for each of the four major stimuli was included in the list. The GSR's for each word were recorded. The purpose behind this step was to determine the extent of the reaction to the words prior to the conditioning process.

At the next experimental session, the combination of buzzer and stimulus-word was begun. Each subject was presented with the reinforced stimulus for four trials during each session. At the end of each day's trials, one presentation of the stimulus-word alone was made to determine whether conditioning had taken place. Experimentation continued until the stimulus-word alone produced a GSR of at least three times the amplitude of the reaction prior to conditioning, on three out of four successive trials.

Immediately following upon the attainment of the criterion, the homophone and the synonym for each conditioned word were presented five times each in random order. The GSR's for these trials were then averaged for each type of word separately. Table I gives the results for all the subjects tested. The number of subjects varies from one set of words to another because some dropped out as a result of the pressure of college work. The subjects were students at Hunter College, all women and in the senior and junior years. None was familiar with the instrument used nor aware of the purpose of the experiment.

All GSR's in the table are expressed in microamperes. Each entry in the post-conditioning column represents the mean of four determinations for each of the subjects in the various parts of the experiment. That is, in the first group of words, each entry represents the mean of sixteen observations and in the second group, of 24 determinations.

Despite the small number of subjects and the variation from one set of words to another, several conclusions seem tenable. The galvanic skin reflex proved amenable to verbal conditioning. Furthermore, with the exception of the first group of words, there is evidence of transference. As in the case of Razran's experiment, the carry-over to the synonym

TABLE I

GALVANIC SKIN REFLEXES CONDITIONED TO FOUR WORDS AND TO A HOMOPHONE AND SYNONYM FOR EACH

Words	No. of subjects	Pre-cond. GSR's	Post-cond. GSR's	Percentage gained from conditioning
Style	4	30	220	633%
stile		15	20	33
fashion		60	80	33
Freeze	6	75	225	220
frieze		25	60	140
chill		80	232	190
Surf	7	100	355	255
serf		45	80	76
wave		55	136	147
Urn	9	125	460	276
earn		135	310	129
vase		90	265	194

Mean gain in percentages for each type of word

Stimulus words	346.0%
homophones	94.5
synonyms	141.0

All GSR's are given in terms of microamperes.

was consistently greater than to the homophone. In both experiments, then, transposal of a conditioned reaction is easier when the verbal stimuli are meaningfully linked than when they are merely like sounding. From these preliminary results, it is apparent that the galvanic skin reflex offers a fertile field for experimentation in semantic conditioning. Research in progress at the moment indicates that a great deal of the variability in the pre-conditioning series may be eliminated by presenting the stimuli on lantern slides or film. In this way, the disturbance occasioned by the movements of the experimenter in presenting the cards will be eliminated. Another innovation that is being studied is the concealment of the connection between the words and the galvanic response. The subject is led to believe that response to shock is being studied and concentrates her attention upon the identification of a minimal shock stimulus rather than upon the reading of a specific word. This results in a loss in the magnitude of the original reflex.

(Manuscript received December 11, 1939)

A NEW APPARATUS FOR VOICE CONTROL OF ELECTRIC TIMERS

BY DAVID P. BODER

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A Voice Key

Some years ago the writer described a set of electronic devices for oral interruption of chronoscope circuits and for the control of kymograph writing pens (1). To the best of his information his photoelectric word counter described in this group has been successfully used by Professor Bills in his study of blocks (2). Since then, the present writer has designed a greatly simplified and more efficient voice key which he has omitted to describe but which has been made available through C. H. Stoelting Co.[1] In view of the fact that new and wider uses appear to present themselves not only for the voice key in its present construction, but for a new combination of the same principle with a loud speaker system, a more detailed description of the instrument shall be given at present.

The principle of the voice key was suggested by a toy, the 'microphone dancer,' which was available on the market some years ago for only a short time. In its modified form (Fig. 1) the apparatus consists of a microphone case which houses the following mechanism: a telephone diaphragm *a*, with a pointer *b*, soldered to its center; a lever of a non-magnetic metal *c*, on a pivot which makes contact with *b* under pressure of a spiral spring *d*, as used in small electric meters the tenseness of which can be properly controlled by a special adjustment. The vibrations of the diaphragm throw the lever *c* in the direction of the arrow breaking the circuit at every accentuated syllable. *This arrangement is sufficient to stop the Dunlap chronoscope or to activate a magnetic kymograph pointer such as*

[1] Stoelting Catalogue, Supplement, 1937, No. 17220.

in the Darrow lie detector. This voice key gives results even when placed at a distance of 8 inches from the subject.[2]

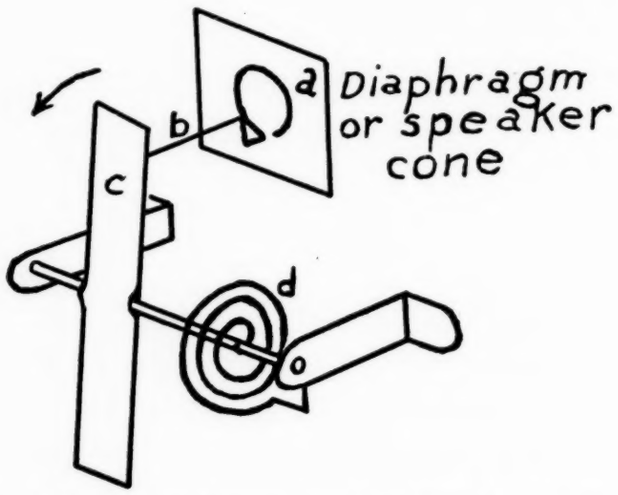

FIG. 1. Voice key mechanism greatly enlarged in part (see text).

CIRCUIT FOR THE VOICE CONTROL OF ELECTRIC TIMERS

Vocal responses especially of the controlled association type take a comparatively longer time than simple finger reactions (**3, 4**). Even for the latter *Rexroad* (**5**) has successfully used a 'Cenco' impulse counter which operates in units of 8.3 ms. (1/120 sec.). It appears, therefore, that electric timers such as the Cenco or as those of the Standard Electric Time Co. which give satisfactory readings in units of 10 ms. may well be suitable for reactions which average more than 300 ms. One of these Standard Electric timers is used by Dr. L. L. Thurstone and it was an incidental conversation with him that prompted the design of the circuit we are about to describe.[3]

We shall give first the circuit for conditions in which *only the response* is given by voice, while the stimulus is of the conventional visual or auditory character of electro-mechanical variety (Fig. 2). The crucial component of the circuit in addition to the voice key, is a Guardian Electric Co. relay [4]

[2] This fact has been checked by Mr. Allen Falkman in connection with a student project in experimental psychology.

[3] The writer is indebted to Professors LeRoy T. Anderson and Victor L. Sherman, and also to Emil Richter, technician, all of the Departments of Engineering of Lewis Institute, for their assistance in the final layout of the apparatus.

[4] Guardian Elect. Mfg. Co., serial no. 19934.

with a double pole, double throw armature. The relay closes at 20–24 volts a.c. (3–6 volts d.c.) 'pulling' voltage and continues to stay closed if this voltage is subsequently reduced to 9–16 volts a.c. (or about 2 volts d.c.). However, if this lower or 'holding' voltage is interrupted transitorily by the voice key, the relay will open and *stay open* even after the voice key closes again the circuit. The reason for this is that the 'holding' voltage is not strong enough to *pull* the relay,

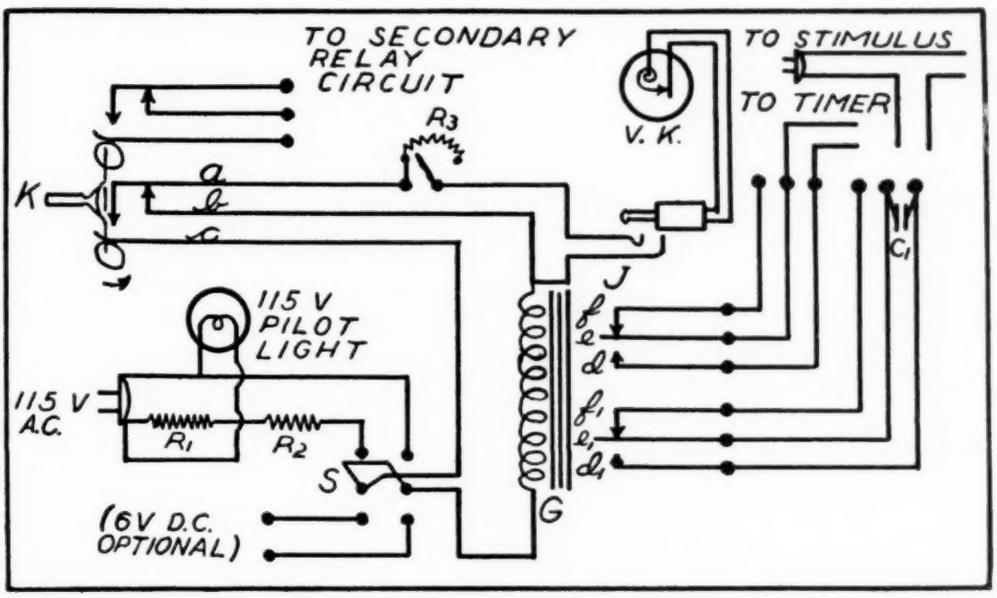

FIG. 2. *K*—lever key, type 'make before break'; *V.K.*—voice key (Boder); R_1—350 ohm resistance line cord; R_2—25 ohm, 20 watts fixed resistor; R_3—600 ohm potentiometer; *G*—Guardian Electric relay, number 19934 with 2 sets of 'break make' springs ¼ of an inch contacts; *J*—open jack; *S*—double pole double throw switch; c_1—2μfd Aerovox filter condenser, type 6 UC, 600 D.C.W.V., optional and depending on load.

once it has returned to an open position due to momentary break of the circuit. The pair of triple spring contacts on the relay take care of the timer and stimulus. The springs *d* and *e* as well as d_1 and e_1 close the respective circuits when the relay is activated. The contacts *e* and *f* as well as e_1–f_1 are free for special uses depending on particular experimental requirements.

The energizing of the relay first with 24 volts and the immediate subsequent reduction of this voltage to below 10 is accomplished by a lever key (Fig. 3) of the type '*make*

before break' used in telephone switch boards.[5] The pressure of this key first closes *c* and *a* without breaking the contact of *a* and *b*; the voltage is transitorily equal to 24 volts; however in the next instant *a–b* are opened and only *a–c* remain closed. The current to the relay now flows through the resistance R_3 and is reduced to about 10 volts a.c. (or 2 volts d.c.). The voice key is in series with this circuit and when the latter is broken for an instant by means of the voice key the relay will stay open until the next stimulus is given. The power for the relay is taken from the 110–120 volts 60 cycle line and is reduced to required voltage by means of a 350 ohm line cord in series with a 25 ohm (10 watt) resistor. The

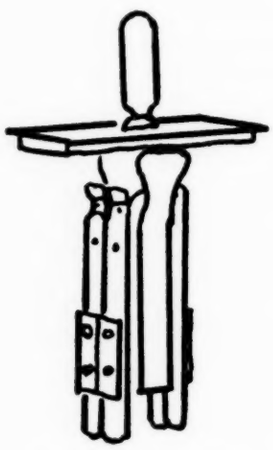

FIG. 3. Lever key.

provision that the relay operates on 6 volts d.c. as well is of special usefulness when the operation of the *stimulus* requires a great amount of current to be taken from the 110–120 line, or when small d.c.–a.c. converters are being used which may deliver only enough a.c. to run the timer.

If the stimulus, as well, is to be given by voice another relay of the same kind with an identical circuit is used. This second relay requires a separate 350 ohm line cord with another 25 ohm fixed resistor in series,[6] or a 6 volt storage battery. The *e* and *f* springs of the second relay are connected in series with *d* and *e* springs of the first (Fig. 4).

[5] Automatic Elect. Co., Z-D321865.

[6] Better results may be obtained without the resistance at all; the stimulus-response situations are usually so brief that the overload will not cause any appreciable damage to the relays.

When then the lever key is pressed both relays close simultaneously and the timer *will not start.* The word of the experimenter spoken into a separate voice key opens relay II. This *starts* the clock. The vocal response of the observer then opens relay I and so *stops* the timer.

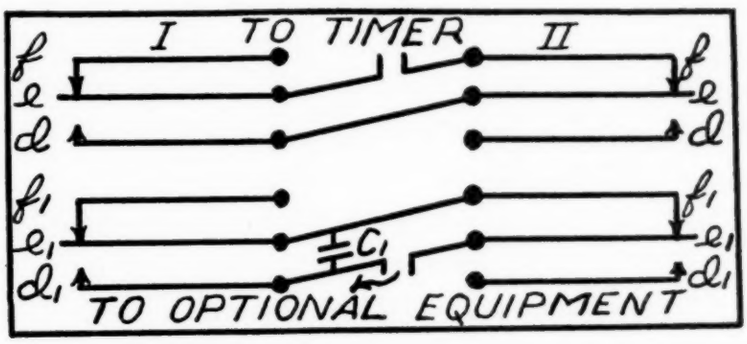

FIG. 4. Connections between springs when two relays are used. I and II designate respective relays.

Only one lever key is used for both relays but it must carry a double set of 'make before break' springs, to be activated simultaneously. When ordering the key the following specifications should be given: (1) the key should *lock* on one side and *not lock* on the other; (2) both sets of springs of the 'make before break' combination should be located on the locking side, one on each side of the handle. It might be useful to have on the non-locking side a set of springs of the *make-break* type for a possible warning signal circuit.

The whole apparatus is housed in a radio cabinet about 14" by 9" by 7". The jacks, rheostats, pilot lights and toggle switches are mounted on the front panel. The relays with six binding posts for each are mounted on a bakelite board which easily slides into and out of the cabinet.

The wires connecting the parts on the front panel with the relays should be long enough to permit easy removal of the relay board from the cabinet so as to facilitate repair, or change of combinations. The D.P.D.T. switches and the lever key are located conveniently on the roof of the cabinet.

FURTHER IMPROVEMENT IN EFFICIENCY OF THE VOICE KEY

When the above described circuits were given their laboratory tests it was found that dozens of voice reactions could be obtained with but a few failures of the apparatus. Nevertheless, incidental failures would occur, especially with words such as *meek*, *Lillian*, *tin*, *except* and others of similar construction. Moreover, all words had to be pronounced with a reasonable degree of sharpness and at the end of a series of 30–40 responses the subjects would manifest some let down due to apparent fatigue or boredom. This defect has now

been remedied by *placing the voice key in the nearest proximity and if possible in physical contact with the loudspeaker of a vacuum tube amplifier.* With the use of a crystal microphone even words spoken in a low voice will come through. If the amplifier is well out of the way intensive amplification is possible without 'howl.' The subject can speak in a normal, non-forced voice, with the microphone several inches away from his face or fastened to his lapel. Proper choice of amplifier will reduce the number of misses to an insignificant minimum.

A further improvement is presented by combining into one unit a 3″ or 5″ permanent magnet speaker with the spring element of the voice key (Fig. 1). In such a device the microphone housing is dispensed with. The diaphragm is fastened to the paper speaker cone with radio cement and the bakelite strip holding the spring unit is screwed on to the speaker frame. As a matter of fact, the pointer can be made of a longer piece of wire with a loop on one end; this loop can be *fastened to the speaker cone directly*, dispensing with the diaphragm also. The slightest vibration of the cone will produce the required break. By means of proper wiring the same amplifier can take care of two microphones and two speaker keys, if both the stimulus and responses are to be vocal. For this purpose relay I controlled by the experimenter keeps the response speaker out of circuit until the stimulus word is spoken; only then the response circuit including the timer is thrown into operation. The response of the subject stops the timer. The return of the lever key to its initial position sets the apparatus ready for the next stimulus.

Conclusions

1. A voice key has been described, which together with great economy in cost gives satisfactory results with the Dunlap chronoscope permitting as well a comfortable distance of the key from the face of the observer.

2. The function of the voice key is greatly enhanced by placing it in immediate contact with a loud-speaker of a conventional inexpensive P-A system. The voice key mechanism may also be directly combined with a loud-speaker unit.

3. A relay circuit has been described which permits the control by voice of electric clock mechanisms driven by commercial current such as those of the Standard Electric Time Co., or the Cenco impulse counter. The circuit is built on the principle of separate 'pulling' and 'holding' voltages for operation of the relays.

4. The relays are of a sturdy type with springs capable of handling more than thousand watts. This makes it possible to use as stimuli pictures or patterns thrown on the screen by means of a projection lantern (personal communication by Professor Thurstone).

5. The circuit permits a hook-up with a motion picture projector in such a manner that the chronoscope or other electric timer will start with the appearance on the screen of a definite frame of a running film, say the appearance of a child or a bicycle rider in front of an automobile. The observer may stop the timer by voice or any suitable device of mechanical character.

6. The described voice key is exceedingly sensitive to vibration. When placed behind a target, and in direct contact with it, it may be used to time responses in terms of arrow shooting, dart throwing, and release of any missile directed toward a fixed target.

(Manuscript received December 7, 1939)

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A SUGGESTED DEVICE FOR DETERMINING EYE DOMINANCE OBJECTIVELY WITH SCIENTIFIC ACCURACY

BY NORMA V. SCHEIDEMANN AND MORRIS W. KANDLE

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All present mechanical devices for determining eye dominance although utilizing the optical principles for eyedness—a small aperture accommodating but one eye's visual line of regard, interposed between the eyes and a fixation point—are influenced to some extent by handedness, accidental accommodation, head position, and head movement. In addition, none can be used satisfactorily in case of infants and animals.

The desirability of an objective means for determining eye dominance with scientific accuracy is obvious. Among other things specificness could characterize the now controversial questions relative to stabilization and innateness of eye dominance, relative frequency of left and of right eye dominance, possibility and frequency of mixed eyedness, and stabilization of eyedness in animals—principally apes, dogs, and cats.

It would seem that a satisfactory instrument for determining eyedness would utilize the optical principles of eyedness and exclude the interfering factors previously enumerated. Such an apparatus the writers believe could be constructed with modest expenditure of effort and no great financial outlay. Not themselves in position to materialize this apparatus the writers herewith present a diagram of the involved factors in hopes some one will utilize them in developing and perfecting a device for determining eye dominance.

The suggested apparatus (see accompanying figure) consists of a motion picture camera, a series of converging shutters, and a source of light fitted into a case. In order not to diffuse the light within the case a partition-board is placed between the camera and the light. It may be found that

the apparatus may have to be rearranged in actual use, but all the essential parts are presented.

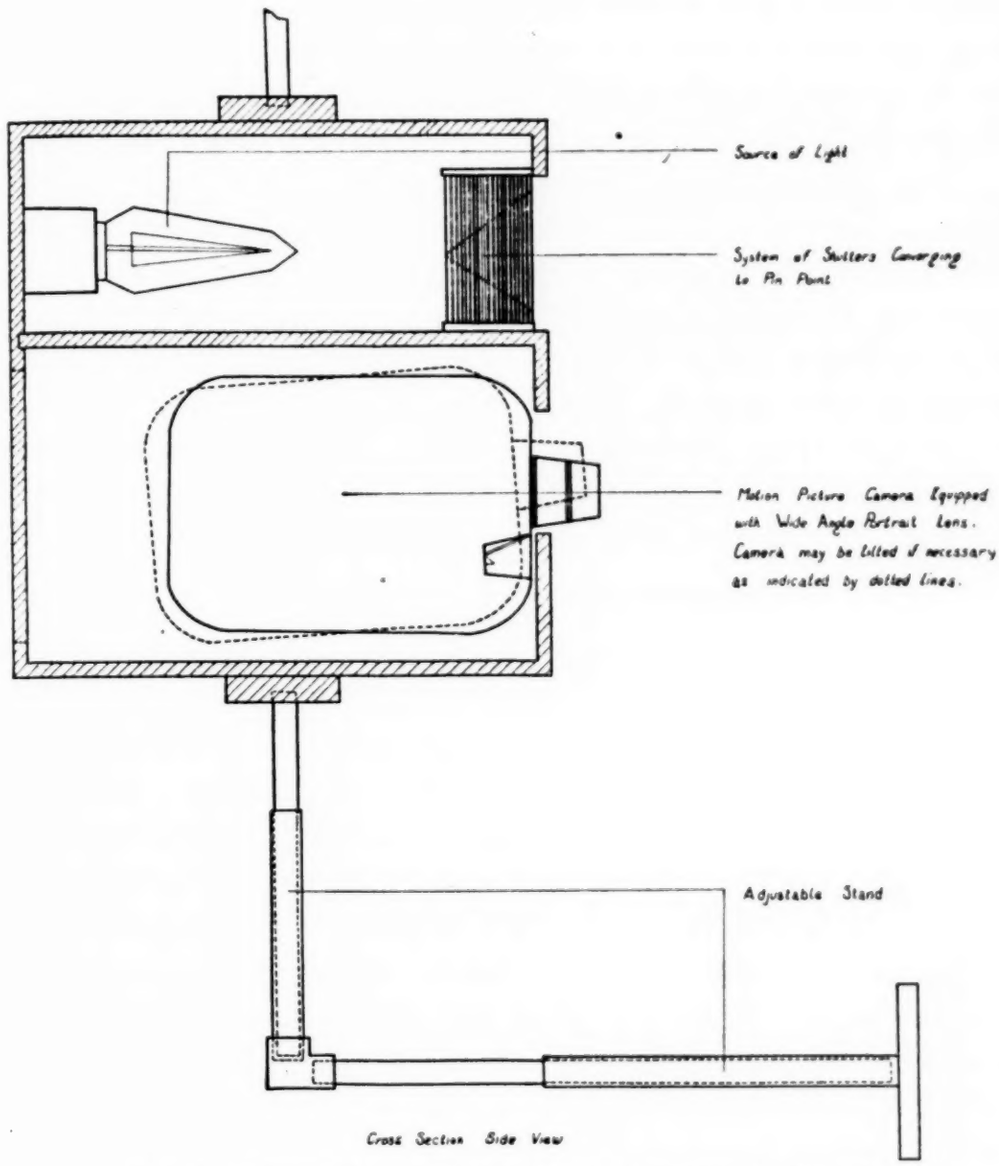
Source of Light
System of Shutters Converging to Pin Point
Motion Picture Camera Equipped with Wide Angle Portrait Lens. Camera may be tilted if necessary as indicated by dotted lines.
Adjustable Stand
Cross Section Side View

FIG. 1. Suggested apparatus for the study of eye dominance.

The light should be intense enough to attract the attention of an infant or an animal, and should be placed behind the shutters[1] so that it may be focussed by the subject.

[1] Carl Zeiss, Inc., 485 Fifth Avenue, New York City, markets highly perfected iris diaphragms of various sizes that can be used here. These diaphragms consist of a number of metal or of vulcanite leaves that can be opened or closed by operating a small lever. When light of considerable intensity is used the vulcanite leaves are not recommended. The cost of iris diaphragms varies from $10.00 to $35.00, according to size. They are not ordered by catalogue number, but are referred to simply under the name of 'iris diaphragms.'

The camera is adjusted so that it records the image of the subject's eyes focussed on the light. It should be equipped with a wide angle portrait lens for close work. If it is found that the camera will not include the desired field when it is set in upright position it can be angled to desired position as shown by the dotted lines.

The camera should be started when the eyes focus the light. While the light is fixated the shutters in the interposed diaphragm are slowly and smoothly drawn inward until the aperture accommodates the line of regard of only one eye. The recorded series of images may then be projected on a screen in slow motion, or each exposure may be developed as a still and then enlarged uniformly. High lights, pupillary changes and possibly other factors may be studied from these records.

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